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Prescribed fire effects on water quality in the Lake Tahoe Basin, California

Dale Yvonne Payne
San Jose State University

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PRESCRIBED FIRE EFFECTS ON WATER QUALITY IN THE LAKE TAHOE BASIN, CALIFORNIA

A Thesis

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by

Dale Yvonne Payne

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Dr. Lynne Trulio, Associate Professor of Environmental Studies, Committee Chairperson

Dr. Lester Rowntree, Professor of Environmental Studies

Dr. Mark Poth, USDA Forest Service, Pacific Southwest Research Station

APPROVED FOR THE UNIVERSITY

ABSTRACT

PRESCRIBED FIRE EFFECTS WATER QUALITY IN THE LAKE TAHOE BASIN, CALIFORNIA

by Dale Yvonne Payne

Forest resource managers must balance the ecological benefits of prescribed burning with potential water quality impacts. This thesis examined nutrient impacts to a stream in the Lake Tahoe Basin to determine the effects of prescribed burning in sensitive riparian areas. Burn and control sites were evaluated along ephemeral streams tributary to General Creek, a mainstem tributary to Lake Tahoe. Streamwater concentrations of selected anions and cations were compared. Samples were collected during precipitation events and snowmelt runoff between November 1996 and June 1997. Calcium concentrations showed significant increases with burning. Phosphate exhibited insignificant concentration increases. Phosphate and nitrate concentrations exceeded water quality criteria in the burned areas; however, these concentrations were not statistically different than those at the control stations. This research found that prescribed fires produced relatively minor changes to nutrient loading, and did not adversely affect water quality at this site.

Key words: Lake Tahoe; prescribed fire; water quality; anion; cation; nitrate; sulfate; phosphate; calcium; magnesium; potassium; eutrophication.

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My brother deserves thanks for the distractions; keep those private eye novels coming.

My most heartfelt appreciation goes to my parents for their support.

This thesis is dedicated to my mother. I wish you were here to read this, Mom. I love you a whole world full.

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INTRODUCTION

Background

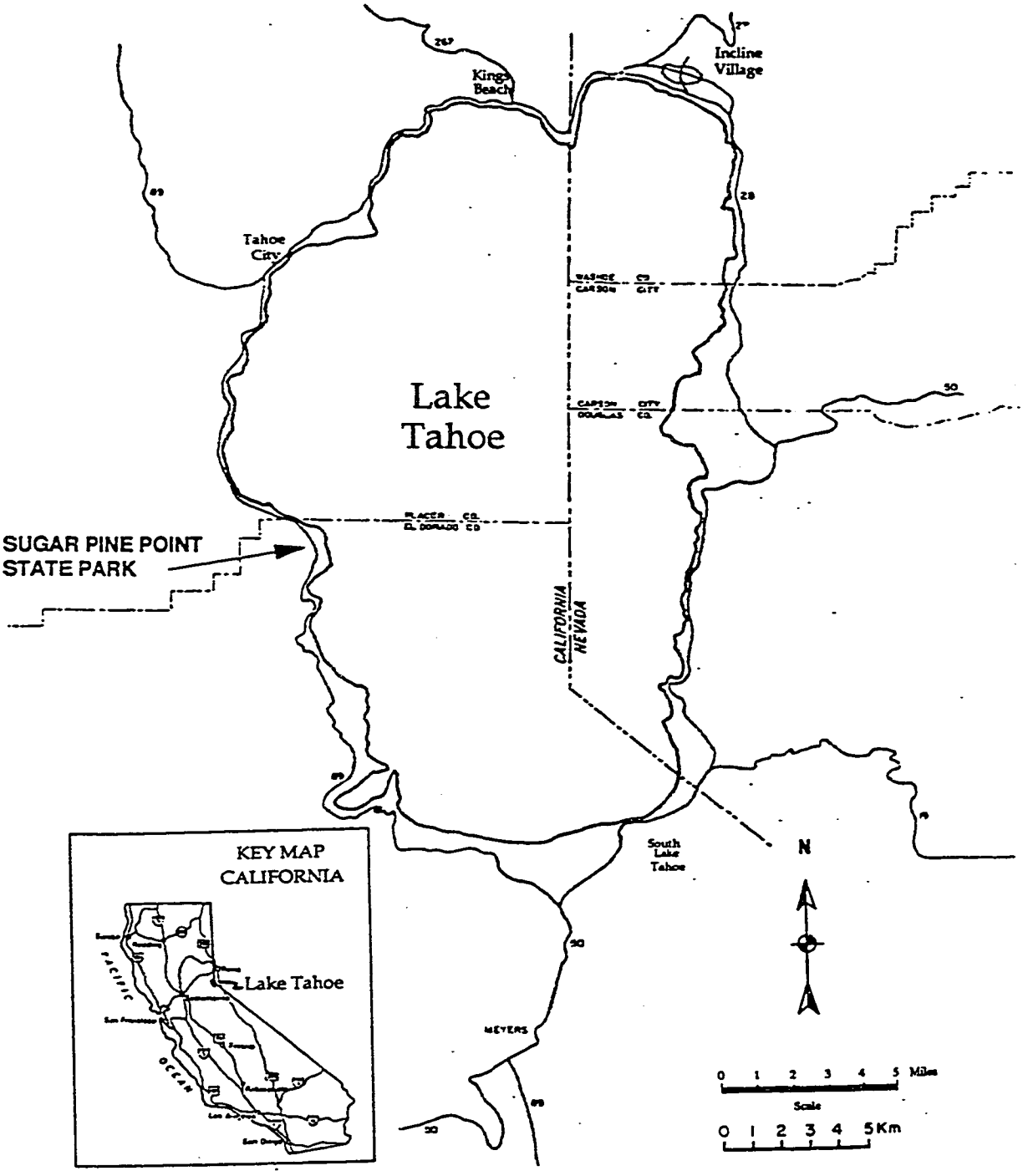
This research focused on the effects of a prescribed burning program on water quality in sensitive riparian habitat. Burns are managed by the Sierra District of the State of California Department of Parks and Recreation (DPR). The study site is located in the General Creek watershed within the boundaries of Sugar Pine Point State Park on the west shore of Lake Tahoe, California (Fig. 1). This study provides a preliminary investigation of the nutrients flowing towards Lake Tahoe from stream water following planned prescribed burning. It offers data on the significance of these activities. The evaluation of nutrients in this study includes an assessment of cation-anion interactions with specific attention to calcium (Ca^{+2}) and phosphate (PO_4^{-2}). These ions are of interest because interactions between them may immobilize phosphorous, a limiting nutrient in Lake Tahoe.

The well-known transparency of Lake Tahoe's water is threatened by the addition of nutrients from tributary streams, urban runoff, and atmospheric deposition. Accelerated primary productivity such as planktonic diatom or algae reproduction is occurring as a result of the increased accumulation of phosphorous and nitrogen in the waters of Lake Tahoe. This process of eutrophication reduces sunlight penetration, disrupts the ecological balance, and decreases water clarity. Eutrophication of Lake Tahoe has been accelerating over the past 40 years due to increased nitrogen and phosphorous entering the Lake from human activities (Goldman 1989).

The secchi depth is a measure of clarity obtained by lowering a secchi disc, a 25 cm white disc, into the water and recording the depth at which it is no longer visible. The transparency of the water will determine the depth of clarity recorded as the disc

Figure 1

SUGAR PINE POINT STATE PARK
GENERAL SITE LOCATION



disappears from view. Recorded since 1967, average secchi depth has shown a decline of 0.40 meters per year, equal to approximately 13 meters of depth (Goldman 1989).

Nutrients impacting Lake Tahoe originate from non-point sources including streams, urban runoff, and atmospheric deposition. Atmospheric inversion caused by the physical features of the Lake Tahoe Basin in conjunction with weather patterns contribute to the trapping of automobile emissions and smoke particles from fires. A majority of the total annual nutrient load to Lake Tahoe of dissolved inorganic and total nitrogen, and lesser amounts of soluble reactive and total phosphorous, are deposited from atmospheric sources on the Lake surface (Jassby et al. 1994; Carpenter et al. 1998). Phosphorous concentrations now exceed the previously existing nitrogen concentrations in Lake Tahoe tributary streams due to soil disturbances. However, deposition of nitrogen compounds from atmospheric sources is changing the balance of nutrients in Lake Tahoe from a system limited by both phosphorous and nitrogen to a primarily phosphorous-limited system (Jassby et al. 1994). As a result, algae have become increasingly sensitive to phosphorous over nitrogen, and phosphorous is replacing nitrogen as the growth limiting factor in Lake Tahoe (Goldman 1989; California Regional Water Quality Control Board 1994).

Human activities in and around the Lake Tahoe Basin have significantly increased the rate of nutrient deposition to the Lake. Development as a result of population growth and seasonal tourism has accelerated this process. The human population in the South Lake Tahoe area grows rapidly during the summer when seasonal residents arrive and additional people visit the area. The South Lake Tahoe population expands from approximately 23,660 to 125,000 people during tourist seasons (El Dorado County 1994). Anthropomorphic additions of nutrients to the Lake may also include atmospheric fallout of particulate matter both from automobiles and

prescribed fire. Smoke may cause a decrease in atmospheric visibility which makes the area less attractive to visitors. Such changes in air and watershed will inevitably alter the natural beauty of this environment, and effect the economy of the Lake Tahoe Basin, an economy that is tied to tourism and recreation based on the Lake's beauty and clarity.

Concern for the fate of Lake Tahoe's water quality initiated the development of federal and regional water quality criteria. Water quality standards in the State of California were initiated under the state Porter-Cologne Water Quality Control Act (Porter-Cologne) of 1970, the Federal Water Pollution Control Act of 1972 (WPCA), and the federal Clean Water Act of 1977 (CWA). These laws established beneficial uses for water bodies, including Lake Tahoe, and set corresponding water quality criteria to protect the most sensitive beneficial uses. The California Regional Water Quality Control Board (Regional Board) has jurisdiction in these matters and regulates water quality criteria in the Lake Tahoe Basin.

The CWA designated Lake Tahoe as an Outstanding National Resource Water and required that no degradation occur within Lake Tahoe. It also states, in Section 114, the need to preserve the fragile ecology of Lake Tahoe (California Regional Water Quality Control Board 1994).

As defined by the Porter-Cologne Act, water quality criteria ensure the protection of public health and maintenance of water quality corresponding to beneficial water uses (McKee and Wolf 1963). Surface water quality criteria determine allowable limits of specific constituents or materials. These, in turn, provide a basis for detection of future degradation or improvement. Measurable criteria within Lake Tahoe include algal growth potential (nutrient concentration), biological indicators, clarity, conductivity, pH, plankton counts, suspended sediment, and transparency. Water

quality objectives established by the Regional Board for Lake Tahoe are as follows: sulfate 1.0 mg/L, total nitrogen 0.15 mg/L, and total phosphorous 0.008 mg/L. Tributaries to Lake Tahoe have their own water quality objectives. These objectives for General Creek are 0.4 mg/L for sulfate, 0.15 mg/L for total nitrogen, and 0.015 for total phosphorous. Criteria have not been determined for other constituents examined in this study (California Regional Water Quality Control Board 1994).

The quality of the Lake's water is closely tied to activities in the watershed, such as prescribed burns which are designed to improve the forest ecology of the Lake Tahoe Basin. Prescribed burning has been shown to benefit sensitive ecosystems and those adapted to fire (Ffolliott, Cabrera, and Guido 1996; Richter, Ralston, and Harms 1982), and its use may promote similar improvements in the Lake Tahoe Basin. An intense period of logging, grazing, and deforestation in the 1880s, and subsequent fire suppression has resulted in increased forest density (Taylor 1997) in the Lake Tahoe Basin. Resource managers believe this density needs to be decreased in the Lake Tahoe Basin to improve forest health and increase species diversity. Forest management using prescribed fire in the Lake Tahoe Basin has focused on: 1) reducing the probability of wildfire (McKelvey et al. 1996), 2) reducing further ecological damage from insect infestation (Baker 1988), 3) rectifying imbalances in species composition, and 4) avoiding property damage (Sackett, Hasse, and Harrington 1995; Husari and McKelvey, 1996). Prescribed fire is beginning to be used as a management tool in the Lake Tahoe Basin to achieve these ecological improvements.

However, fire may also have some negative ecological impacts. Potential adverse environmental effects from prescribed burning may include reduced visibility from smoke production, reduced water quality from addition of nutrients to surface water, and increased contact between areas of wildland burning and urban areas.

Researchers investigating prescribed burns and their effects on nutrient movement and water quality have produced varied results. While few studies have shown long-term detrimental effects (Lewis 1974; Tiedmann et al. 1979; Wright, Churchill, and Stevens 1982; Richter, Ralston, and Harms 1982; Baker 1988; Davis 1989; Gottfried and DeBano 1990), Baker (1988) states that the influence of fire on nutrient movement is unclear. He suggests that further investigations should study effects on riparian habitat, watershed condition, and cumulative effects of site productivity.

Water quality managers worry about the effects of prescribed burning, because the soil chemistry involved is complex and not thoroughly understood. Nutrient discharge to surface waters may be inhibited by processes such as changes in pH and ion exchange which have the potential to immobilize soluble ions that are produced by burning. These ions would then be unable to percolate through soil to reach surface water. On the other hand, prescribed fires have the potential to create an imbalance of ionic composition in the soil and cause leaching (Wells et al. 1979). Additionally, prescribed fires are capable of inducing soil erosion, resulting in nutrient loading and reduced water quality (Wright, Churchill, and Stevens 1982). The protection of water quality must be considered when planning resource management programs, such as prescribed burning.

Water quality disturbances resulting from manipulation of forest ecosystems have been examined over the last three decades in the Lake Tahoe Basin, but there is a need for baseline information and data on nutrient movements after prescribed fire. This information is essential to developing integrated watershed management plans.

Research questions

This thesis research collected data on the effects of prescribed fire on nutrient loading in ephemeral streams tributary to General Creek. Six soil constituents, sulfate (SO_4^{-2}), nitrate (NO_3^-), phosphate (PO_4^{-2}), calcium (Ca^{+2}), magnesium (Mg^{+2}), and potassium (K^+) were measured at burned and non-burned sites throughout winter (1996) and spring (1997). The following questions were answered:

1) Was there a significant difference in constituent concentrations between the treatment (burned) and control (unburned) units?

2) Was there a significant difference between on-site (burn) and upstream (above burn) constituent concentrations?

3) Was there a significant difference in constituent concentration between the east and west burn stations?

4) Was there a significant relationship between phosphorous and calcium within the burn stations?

5) Did precipitation events influence concentration or availability of nutrients at the burn or control units?

Findings of this master's degree project provide important information about nutrient loading as a result of prescribed fire in a managed forest of the General Creek watershed. This analysis offers useful information for many agencies and organizations in the Lake Tahoe region which are concerned with resource management, environmental regulation, or protecting the clarity and beauty of Lake Tahoe. To date, prescribed burning has not been shown to contribute to the water quality problem in Lake Tahoe. Information from this study may benefit the development of resource management programs in the Lake Tahoe Basin and similar ecosystems. Results of this study are useful for numerous local and regional agencies and organizations, and may

offer assistance in guiding objectives and goals for resource management programs. Agencies that may use this information are the USDA Forest Service, California Department of Parks and Recreation, California Tahoe Conservancy, State of California Water Quality Control Board-Lahontan Region, Tahoe Research Group and Lake Tahoe Interagency Monitoring Program, Tahoe Regional Planning Agency, California Department of Forestry and Fire Protection, Natural Resource Conservation Service and Natural Resource Conservation Districts of Tahoe/Nevada-Tahoe, and the Nevada Department of Conservation and Natural Resources and Division of State Lands. This study may be helpful in evaluating water quality issues in other sensitive environments such as wetlands, riparian areas, or lakes.

RELATED RESEARCH

Sierra Nevada fire history

Burning is considered to be the most notable anthropogenic mechanism changing the ecology of the Sierra Nevada (Laudenslayer, Darr, and Smith 1989). There is evidence that the native American Washoe Tribe manipulated the ecosystem with fire for a period of over 1,300 years; however, the full extent of this influence is undetermined (Elliott-Fisk et al. 1996; Skinner and Chang 1996). According to Skinner and Chang (1996), native Americans had three major reasons for using fire as a management tool in their environment: enhancing the production of food through insect control, allowing greater acorn yield; ensuring the availability of basket weaving materials through the regeneration of immature plant stalks; and reducing the severity of larger fires that could eradicate food supply.

Records show that fire suppression began in the Lake Tahoe region with the onset of the Comstock Era and the initial settling of the area by Europeans in the late 1800s; however, earlier accounts show that Spanish law eliminated the Native American use of fire because the burning of understory depleted forage for horses and livestock (Skinner and Chang 1996). Historically, fire exclusion in forested areas of the Lake Tahoe Basin occurred to eliminate damage to valuable trees (Skinner and Chang 1996). During the Comstock Era, mineral mining was peaking in Nevada. Several large logging firms were formed in the 1870s to supply timber for mine shaft supports. The nearest source of wood for this purpose was found in the area of Lake Tahoe. The logging firms aggressively acquired land and cut timber as quickly as possible; up to 72 million board feet were cut in one year to supply mine demands. Supplying lumber to the mines proved more profitable than the mines themselves. Demand for timber remained high through the 1890s. Deforestation of the most

accessible areas of virgin timber in the Lake Tahoe Basin occurred first and was completed by 1888. Nearly the entire Lake Tahoe Basin was logged (Tahoe Regional Planning Agency, 1971).

As the forest grew back in the Basin, fire suppression led to dense tree regrowth. This dense growth has increased the potential wildfire threat to the forest and neighboring urbanized areas. It has resulted in low diversity of forest tree species as well as severe outbreaks of insect infestation and related botanical diseases. It is now evident that fire exclusion and suppression add to the risk of wildfires as the density of forest stands increase and fuel loads build (Grier 1975; Skinner and Chang 1996; Elliott-Fisk et al. 1996). Consequently, forest management agencies have begun to realize the benefits of prescribed burning programs, but they need to understand all the consequences of this management activity.

Historical forest density was much lower than what exists today in the Lake Tahoe Basin. Naturally occurring low intensity burns occurred without catastrophic consequence; understory vegetation burned and trees were scorched but an individual fire did not burn vast areas (Taylor 1997).

Restoring pre-settlement forest ecological structure by implementing prescribed fire is a partial aim of resource managers in the Lake Tahoe Basin. To do this, knowledge of the historical forest characteristics including species composition, age and size-class distributions, density, and spatial patterns is necessary (Taylor 1997). Fire history studies are useful in estimating these characteristics.

The fire history of the Sierra Nevada and the Lake Tahoe Basin can be reconstructed from written records, historical accounts, analysis of charcoal in sediments, and dendrochronology (tree-ring analysis). Describing fire scars using a crossdated dendrochronology technique is widely used in fire history studies (Skinner

and Chang 1996). Interpretation includes the crossdating of each fire by season of occurrence, fire spread, return interval, size and extent patterns, and severity of a given fire (Taylor 1997; Skinner and Chang 1996). Dates of a given fire can also be compared with climatic data to deduce regional fire climatology (Caprio and Swetnam 1993). Furthermore, smoke production of pre-suppression fires can be predicted by referencing the historic fire regimes. Such information could approximate potential air quality effects of current prescribed burning programs (Taylor 1997).

Fire-adapted ecosystems such as the forests of the Sierra Nevada are dependent on fire for periodic changes. Fires change vegetation, nutrients, spatial components, and ecosystem functions (Mutch 1995). Some systems may reveal a regular pattern of fire occurrence where this disturbance is an essential component. These natural fire patterns are termed fire regimes. Fire regime characteristics include fire type, size or area, frequency or return interval, rotation, and seasonality. Fire return interval is the number of years between repeated burns in a specific area. The length of time it takes to burn such an area is called fire rotation (McKelvey et al. 1996). A given fire regime in the Sierra Nevada will vary depending on vegetation type, fuels, and microclimate. Representative fire regimes of the Sierra Nevada included low to moderate severity fires covering large areas, with some segments reaching higher severity (Skinner and Chang 1996).

According to a fire study conducted in the Sierra Nevada in six California State Parks, including Sugar Pine Point State Park and two others in the Lake Tahoe Basin, fire return intervals averaged every 5 years in the Sierra Nevada between 1800-1899; for the years 1900-1990, the return interval averaged 20 years (Elliott-Fisk et al. 1996). Low severity fires lacking hot, damaging crown fire characteristics were the historic fire regime in the Sierra Nevada (Caprio and Swetnam 1993). Skinner and Chang

(1996) have indicated that forests of the Sierra, including the Lake Tahoe region, supported frequent low to moderate severity fires in the past. Fire return intervals ranged from 3-44 years before 1850, and 3-114 years after this date. Studies by Taylor (1997) on the east side of the Lake Tahoe Basin reveal earlier historical accounts including frequent fires with the mean fire interval for 1597-1871 to be 6.5 years, ranging between 1 and 32 years. Fires noted in this study were mostly small, low severity surface fires. Larger fires were noted in 7 separate years, showing a return interval of approximately 21 years. Taylor's study spanned a total of 400 years of history. No fires occurred in the General Creek study area since the Comstock Era in the early 1870s.

Many policy makers and researchers believe prescribed fire should be used in conjunction with other treatment methods as a beneficial tool in resource management, and that fire should be more widely implemented to assist in the control of wildfire hazards (Babbitt 1996; McKelvey et al. 1996). Fire policy and management vary from state to state; however, federal wildland fire policy and management recommendations are uniform. The policies of the U.S. Department of Agriculture and U.S. Department of the Interior include protection of human life, reintroduction of wildland fire into the ecosystem, organizational coordination between agencies, pre-treatment used when wildland fire reintroduction is inappropriate, and a Fire Management Plan for every burnable area (United States Department of Agriculture and United States Department of the Interior 1995).

A unique example of regional government regulation exists in the Lake Tahoe Basin. In addition to the Regional Board the Tahoe Regional Planning Agency (TRPA) regulates environmental laws in the Lake Tahoe Basin including California and Nevada sides of Lake Tahoe. Both agencies require water quality objectives to be met;

however, TRPA has jurisdiction over development and watershed disturbance in the Lake Tahoe Basin. The TRPA sets guidelines stated in the Code of Ordinances which govern how prescribed burns can be conducted (Tahoe Regional Planning Agency, 1987). This document limits prescribed burning procedures to beneficial management activities including seral stage manipulation, fuels reduction, wildlife habitat enhancement, silvicultural activities, and pest control. This document also states requirements for prescribed burning including: 1) spatial extent of a burn shall be limited to the area necessary to achieve the burn prescription; 2) a burn shall be scheduled during accommodating weather patterns to allow for smoke dispersion; 3) the burn prescription shall be prepared by a qualified expert and the burn shall be overseen by this expert; and 4) applicable protocol shall be followed in accordance with other government agencies with jurisdiction.

Managing prescribed fire

Fire has direct and indirect influences on many forest ecosystem components (Agee 1993). Decreased transpiration occurring as a result of vegetation removal can effectively increase stream flows. This has the potential to dilute nutrient concentrations in streams and conceal the results of burning on water quality. Vegetation loss also disrupts the uptake of nutrients and results in increased nutrient runoff to streams or leaching to soil. Alteration of a balanced nutrient cycling disrupts ionic exchanges within soil and causes increased leaching of nutrients into soil and eventually to streams.

Combustion processes are rapid and depend on fuel, heat, and oxygen availability for occurrence (Agee 1993). Moisture is also an important component of the combustion process. Prescribed burns have been reported to burn at 160 - 165°C at

the soil surface (Agee 1993); however, determining a characteristic temperature that a given type of fire will burn is difficult given the above variables. Additionally, a low to moderate intensity fire may combust more rapidly or in bursts if a concentrated amount of fuel exists within a certain area.

The U.S. Department of the Interior and Department of Agriculture (1995, pg. 13) define prescribed fire as "the deliberate application of fire to wildlands to achieve specific resource management objectives." Agee (1993, pg. 418) defines management ignited fire or prescribed fire which includes components that determine the characteristics of a given treatment as "a fire ignited under known conditions of fuel, weather, and topography to achieve specified objectives." Comprehensive burn plans are necessary in order to establish desired results. Prescribed natural fire is defined by Agee (1993, pg. 418) as "a fire ignited by natural processes (usually lightning) and allowed to burn within specified parameters of fuels, weather, and topography to achieve specified objectives."(pg. 418) Ignition source will determine whether a given fire is a prescribed natural fire, ignited by a natural source such as lightning, or a prescribed fire, ignited by resource managers (McKelvey et al. 1996).

Prescribed fire has been introduced into limited areas of the Lake Tahoe Basin to assist in fuel reduction, regeneration of beneficial vegetation, and other management objectives. Prescribed fire was introduced at D. L. Bliss and Sugar Pine Point State Parks in the Lake Tahoe Basin by the California Department of Parks and Recreation (DPR) in 1992 for purposes of renewing forest health and enhancing wildlife habitat (Walter 1996). This prescribed burn program is scheduled to continue until resource management objectives are met.

There are many advantages to using controlled burns. Restoration of fire into the ecosystem enhances and protects natural habitat conditions (Walter 1996).

Reducing fuel loads, for instance, has a direct effect of decreasing the threat of wildfire outbreaks. Because prescribed fires burn with low to moderate intensity, they burn incompletely, resulting in an irregular mosaic pattern of vegetation. The creation of mosaic vegetation patterns and different stages of community succession is beneficial for biodiversity and wildlife cover. Fires of this type also increase sunlight penetration to the forest floor by reducing the understory density, and eliminating shade-tolerant species. Additional nutrients and water are then available for surviving plants. Native vegetation may reestablish as competition for resources decrease (Richter, Ralston, and Harms 1982; Ffolliott, Cabrera, and Guido 1996; Walter 1996). Exposing mineral soil through combustion of the forest floor assists with germination of fire-dependent native species (Walter 1996). Burned vegetation releases chemicals that can also be useful to plant growth; nutrients that are released become available for uptake by newly established or surviving vegetation. Initiation of favorable physical and chemical interactions in soil can occur when soil is heated during fire.

Prescribed fires, if managed properly, are generally of low to moderate intensity and are capable of burning with lower temperatures and shorter flame height for a controlled period of time. Potential benefits include the promotion of ecological processes and forest health through generation of healthy and functioning forest stands under a controlled setting (Williams 1995; Sackett, Hasse, and Harrington 1995). Fires of this type replicate the historical naturally occurring fires in the Sierra Nevada (Taylor 1997).

In comparison to prescribed fire, both slash burning and wildfire exhibit more detrimental effects overall. Slash burning occurs when piled remains of forest harvesting are ignited. These fires are hot, concentrated, and often exhibit high surface and sub-surface temperatures. Wildfires are unplanned burns which are caused by

lightning strikes, and out of control campfires or prescribed fires. Wildfires burn with similar characteristics as slash fires, although uncontrolled, and tend to be more catastrophic with greater burn intensity and duration (DeBano, Ffolliott, and Baker 1996; Lahontan 1995). Wildfires may develop into crown fires that completely consume trees in a blaze. Disruption of hydrology, vegetation, and soil structure may reduce ecosystem stability or a forest system (DeBano, Ffolliott, and Baker 1996).

Water quality effects occurring with wildfire and slash burning have been more widely researched than the results of prescribed burns. These data have limitations because of the large differences between these fires and prescribed fire. Researchers studying wildfires and slash burns have determined varied and inconclusive effects of these events on water quality (Johnson and Needham 1966; Snyder, Haupt, and Belt 1975; Campbell et al. 1977; Stednick, Tripp, and McDonald 1982; Winzler and Kelly 1982; Rinne and Neary 1996; Hauer and Spencer 1998); however, a majority of these results revealed short-term or insignificant effects to water quality from elevated nutrient concentrations. Decreases of cations were found to occur after wildfire (Campbell et al 1977; Stednick, Tripp, and McDonald 1982), with either no changes or insignificant changes occurring in stream water. Seasonal trends were shown to play a role in the dilution of nutrients after fire, which contributed to the negligible stream water quality effects (Johnson and Needham 1966; Snyder, Haupt, and Belt 1975). Winzler and Kelly (1982) conducted research which indicated no changes in stream water quality after slash burning at a northern California site. However, because baseline conditions were not measured and post-burn data were omitted, the results are inconclusive at best. Rinne and Neary (1996) found evidence of long-term degradation of water quality after burning within a southwestern U.S. watershed. Increased concentrations of anions in stream water were evident. Post-fire precipitation

contributed to this loading with erosion and leaching events.

Forest ecology

Fire has direct effects on forest nutrient cycling. Understanding fire and non-fire nutrient ecology is critical to this research. Chemical parameters measured in this study are indicators of fire effects on soil chemistry, stream water quality, and ultimately the condition of waters entering Lake Tahoe. Nutrients of interest include nitrate (NO_3^-), phosphate (PO_4^{-2}), sulfate (SO_4^{-2}), calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^+).

It is widely accepted that nitrogen is the most limiting nutrient for forest growth (Johnson et al. 1982; Marion 1982). Nitrogen and phosphorous are also recognized as limiting nutrients in Lake Tahoe and play important roles in water quality degradation. The presence of these limiting nutrients in the Lake is known to cause undesirable algal blooms and increased phytoplankton production. The nitrate and phosphate forms of these two elements are addressed in this study.

The nutrients listed above are commonly evaluated in soil and water quality investigations. Nitrogen and phosphorous are present in small amounts in soil with large proportions of these nutrients unavailable for plant uptake. Phosphorous is often insoluble; interactions with other elements may render this nutrient insoluble. Sulfur occurs in approximately the same proportions as phosphorous, but it is much more available for plant use. Inorganic sulfur is not made insoluble through reactions with other elements or compounds. Primarily organic forms of nitrogen, phosphorous, and sulfur are found in soil. Although more organic than inorganic forms of sulfur persist in soil, both occur. Decomposition of organic matter converts these nutrients to inorganic forms which are then more available for use by vegetation. In the

decomposition process, organic nitrogen is converted to nitrate in a series of steps that include ammonium conversion to nitrite and finally to nitrate. When calcium phosphate interacts with water and carbon dioxide, it initiates a decomposition process creating water-soluble phosphate and calcium bicarbonate as end products. Each of these products are available for plant uptake or ion exchange in the soil. Phosphorous will be absorbed by roots and less will be lost through soil leaching (Buckman and Brady 1960).

Concentrations of calcium, magnesium, potassium, and sodium will differ based on existing soil type. Potassium is often more abundant than phosphorous unless sandy soils are prevalent. Soil will tend to be acidic with a lack of calcium. Magnesium is similar in function to calcium. These nutrients are commonly found in inorganic forms in soil. Potassium and magnesium usually occur in forms not readily available to plants. Calcium is easily moved through ion exchange mechanisms; it can take the place of hydrogen ions on soil colloids, and be replaced by the same mechanism. Calcium tends to be adsorbed on soil colloid surfaces in larger amounts than magnesium or potassium. As cations are adsorbed and displace hydrogen ions during this ion exchange process, pH increases causing a corresponding decrease in soil acidity. The soil weathering process releases potassium. Potassium is available for plant uptake but may be lost through leaching or can be held by soil colloids in the ion exchange process. Exchangeable ions may be leached from surface soil layers with large precipitation events (Buckman and Brady 1960).

Ammonium ions can be completely oxidized to nitrate by microorganisms in soil or water (United States Environmental Protection Agency 1986). Nitrification of ammonium to nitrate can also occur within heavy snowcaps (DeBano, Ffolliott, and Baker 1996). Marion (1982) found that nitrification occurred with increased moisture

during winter. The U.S. Environmental Protection Agency has set the federal standard for the nitrate and nitrite form of nitrogen at 10 mg/L to ensure public health. Non-point sources of nitrate include atmospheric fallout (dry fall) automotive exhaust, and natural cycling such as mineralization of soils (United States Environmental Protection Agency 1986).

Phosphate is a product of phosphoric acid decomposition in soils. Inorganic sediments may potentially move relatively large amounts of phosphorous from terrestrial to aquatic ecosystems where there is no physical vegetative or soil chemistry buffering. However, phosphorous is not readily available to freshwater primary producers because phosphate forms adsorb to clay particles of sediments and are immobilized in freshwater systems (Childers and Gosselink 1990). Although no federal water quality limit exists for phosphate, concentrations within streams should be below 0.050 mg/L at the confluence with lakes, and within lakes should be below 0.025 mg/L in order to prevent accelerated eutrophication (United States Environmental Protection Agency 1986). Increased pollutant limits are required in the Lake Tahoe Basin where phosphate has been shown to be a limiting factor in the Lake waters (Goldman 1989).

Soil ion exchange is ongoing and will be balanced in stable systems. Hydrogen ions displace cations from exchange sites within the soil (decreasing pH and increasing soil acidity) and bicarbonate-cation solutions leave the system (Agee 1993; Marion 1982, Johnson et al. 1982; Tiedmann et al. 1979; McColl and Cole 1968). This process is continually occurring; however, when cations are released by fire or ash, the cation exchange process is altered. Hydrogen ions can be displaced by additional cations entering the system which will have the opposite effect of increasing pH and reducing soil acidity (St. John and Rundel 1976).

Bicarbonate ions act as transporters of cations through the soil. In cold environments, carbonic acid may form when snowmelt occurs, producing bicarbonate through a series of reactions. If low precipitation occurs in these climates, carbonic acid formation and subsequent dissociation into hydrogen and bicarbonate ions may be reduced, thereby decreasing the potential of cations to leach through the system (Johnson et al. 1982). These circumstances will inhibit the transport of cations to surface waters through the retention of cations in the soil.

Organic nutrients are transformed to inorganic forms through the mechanism of combustion, a process which contributes an additional source of these nutrients to the system (DeBano and Dunn 1982; Johnson et al. 1982) and increases primary productivity and eutrophication. Fire releases more anions and cations than decomposition or chemical weathering (Marion 1982). Additional nutrients in the system may subsequently effect water quality. However, the soil system is complex, and ion exchange within the soil or other chemical interactions might reduce or remove nutrients that have the potential to enter surface waters.

Fire-induced changes

Fire can affect nutrient cycling in part through the combustion of vegetation, volatilization of organic matter, heating of soils, deposition of ash, and solubility of nutrients. As organic matter, vegetation, or portions of the forest floor are burned, nutrients are released (Sackett, Hasse, and Harrington 1996). Complex soil reactions occur with heating and burning of vegetation and organic matter. Major chemical changes occur through leaching of ions from the deposited ash layer on the soil surface (Grier and Cole 1971).

Above ground biomass and nutrients are readily combustible; after burning, these environmental components will determine the extent of nutrient impacts (Boerner 1982). Burning organic matter releases nitrogen, phosphorous, sulfur, and carbon. Burning also increases the mobility of large amounts of calcium, magnesium, sodium, and potassium (Marion 1982; DeBano and Dunn 1982; Agee 1996) and deposits ash on the soil surface. In pinyon-juniper woodlands, DeBano and Klopatek (1988) determined that, through the burning of organic matter and the loss of carbon, biologically available phosphorous would be reduced and ionic forms will remain in ash. Nutrients are transferred to soil through ash deposition and leaching which initiate reactions within soil. Leaching of ash creates an initial flush of elements which tapers off over time. Increased concentrations of anions displace cations from ion exchange sites in the soil which may result in leaching to surface waters. Leaching losses of cations are also dependent on anion formation in the soil, such as bicarbonate, nitrate, or sulfate (Wells et al. 1979). The burning and leaching process also increases soil pH (DeBano and Dunn 1982; Agee 1996).

Nutrient solubility may be altered by fire and have effects on the soil system. Soluble nutrients are created through ash leaching and ionic exchange reactions in the soil (Johnson et al. 1982). Precipitation influences the movement of constituents from ash residues into the soil depending on the volume of water percolation (Grier 1975). Cations will react with water or carbon dioxide to become bicarbonate which will act as a carrier of other cations from the soil system (Tiedmann et al. 1979). Mobilization of nutrients in one study created an imbalance in other soil nutrients which accelerated leaching (McKee 1982). Soil structural changes with fire altered phosphate solubility through vaporization of water from soil, and allowed it to leach from the system (White, Thompson, Gartner 1973). Additional nutrients may leach through the soil

when increased solubility occurs and cation exchange is at its peak (Smith 1970). Other changes in soil ion exchange occur simultaneously, such as hydrogen ion reactions with oxides from leached ash which reduce acidity (increasing pH) and buffer the system. The amount of ash deposited and the buffering capacity of the soil are the main mechanisms of pH change (Raison 1979). Phosphorous was rendered unavailable when it was immobilized in upper soil layers (Nissley, Zasoski, and Martin 1980). Increased pH alters soil affinity for nutrient retention. Cation exchange increases with an increase in pH. Anion interactions are attributed to the exposure of positive charges from cations adsorbed on soil colloids. This is important in phosphate retention (Buckman and Brady 1960).

This influence of ash is the basis of the USDA Forest Service hypothesis which suggests that the interaction between calcium and increased pH cause the immobilization of insoluble phosphorous that might otherwise runoff to surface water or percolate through soils (McGurk et al. 1997). The reactions of phosphorous with water and other elements in the soil may induce insolubility of phosphorous over time, and may have the potential to be retained by soils. In the prescribed fire study, the mechanisms explained above caused the adsorption of phosphorous by calcium carbonate or rendered phosphorous insoluble when precipitated with calcium compounds in the soil (DeBano and Klopatek 1988).

Regardless of fire type, soils heat to certain depths determined by intensity and duration of a given fire. Soil moisture can play a role in heat penetration. Dry conditions reduce the depth of soil heating. Infiltration capacity, the ability for water to percolate through soil, is often affected with heat. Repellency can be caused by volatilization of water repellent compounds found in accumulated organic matter, and when distributed in soil can form a water repellent layer (DeBano 1981; Brock and

DeBano 1988). In some studies, soils have exhibited reduced infiltration capacity through extreme heating (Cory and Morris 1969; Klock and Grier 1979); however, other examinations of light burning have shown short-term reductions (Shubert, Adams, and Richey 1975). If changes in wettability and infiltration are severe, water quality of streams may be affected by nutrient loss due to surface runoff and erosion (DeBano et al. 1967). Interactions between existing conditions including soil type and texture, soil water content, and above ground fuels determine whether this soil characteristic will be affected by burning (DeBano 1981). Research in forested areas of the Sierra Nevada reported high infiltration rates after prescribed fires of low intensity; runoff and erosion were not affected (Agee 1973).

Volatilization is a major pathway of nutrient loss with fire. Rapid evaporation of some nutrients will occur (Wells et al. 1979), other constituents are left behind in ash. Nitrogen is easily lost through volatilization and leaching and is most likely to be a limiting nutrient in the forest ecosystem (DeBano and Dunn 1982). The remaining nitrogen in nitrate form is highly soluble and has the ability to react with cations and may leach to surface water (DeBano, Ffolliott, and Baker 1996). Without the loss to the atmosphere, high concentrations would occur in soil and subsequently would leach to streams (DeBano and Neary 1996). Nitrogen remaining in unburned organic matter is readily mineralized by soil microorganisms.

Research by Davis (1989) shows that constituents mobilized by fire events will enter surface water if there is a lack of vegetation to assimilate nutrients; this effect is exacerbated when large runoff events occur. Additional nutrients may be immobilized within the soil or leached by subsurface flow to surface water (Sackett, Hasse, and Harrington 1996; DeBano and Neary 1996; Grier 1975; DeBano and Dunn 1982). DeBano and Neary (1996) assert that low concentrations of ions normally occur in

streamwater because of a highly interactive system of nutrient exchange between soil and vegetation. Therefore, if adequate vegetation exists for nutrient uptake or if soil immobilizes nutrients, fire may not cause a water quality problem (DeBano and Dunn 1982). Nutrients were transformed into highly mobile ions with fire (DeBano, Rice and Conrad 1979). Additional ions were shown to alter the ionic balance and immobilize nutrients (Lewis 1974). However, fire may interrupt plant uptake of nutrients by the removal of vegetation, and can result in elevated ion concentrations in the soil. Fire has the potential to induce the establishment of vegetation on a burned site with bulk additions of nutrients (Stark 1977).

Vegetation may act as a temporary sink for some nutrients (Stark 1977; Harris and Covington 1983), and will respond quickly to the release of nutrients by low intensity fires (McColl and Grigal 1975; and McColl and Grigal 1977; Wells et al. 1979). Reduction of the duff layer and exposure of the mineral soil may also play a factor in plant responses after fire (Harris and Covington 1983). Fire plays an additional role in the germination of fire-adapted species. Greater seeding establishment and growth occurred in burn plots in comparison to control plots after prescribed burning in a number of studies (Snyder, Haupt, and Belt 1975; Ffolliott, Clary, and Larson 1977; Stark 1977; Sackett, Hasse, and Harrington 1996; and Harris and Covingon 1983). Nitrogen fixation by plants and microbes is also positively affected by prescribed burning (Jorgensen and Wells 1971; Wells et al. 1979).

These factors all interact in each watershed and the effects of prescribed burns on nutrient additions to streams are not easy to predict. However, prescribed fire research has consistently shown small or negligible changes to ecosystems. Ecosystem productivity and enhancement of the soil environment were shown to increase with prescribed burning (St. John and Rundel 1976; Covington and Sackett 1986; Covington

and Sackett 1988) and nutrient additions (Waldrop et al. 1987). Short-term or negligible effects to soil nutrients were often dependent on cation-anion interactions. Lewis (1974) determined increases in nitrate and phosphate concentrations the first rain event following fire. Subsequent rains failed to produce elevated concentrations of these ions. The first precipitation event following burning resulted in increased phosphate and nitrate concentrations in stream water, but subsequent events did not show elevated concentrations (Binkley et al. 1992). Limited duration of water quality effects from prescribed burning were shown by Gottfried and DeBano (1990); results of snowmelt sampling revealed nutrient concentration changes for ten to twenty days. Other studies showed a reduction of nutrient concentrations within weeks or months after a burn treatment (Lewis 1974; Gottfried and DeBano 1990); in many cases a relatively rapid return to pre-burn levels was observed (DeBano, Ffolliott, and Baker 1996). Elevated nutrient concentrations decreased greatly with the first precipitation event after wildfire, dropping lower than control site concentrations (Campbell et al. 1977). Nutrient concentration returned to pre-fire concentrations after one year in a prescribed burn study by DeBano and Klopatek (1988). Potassium returned to pre-burn levels in one year after within an area that was clearcut and slash burned (Snyder, Haupt, and Belt 1975). McColl and Grigal (1975 and 1977) noted greater nutrient concentration in an unburned watershed compared to a burned watershed the third year after wildfire occurred. Significant increases in nutrient concentrations were shown in a study by McColl and Grigal (1975 and 1977); however, these concentrations decreased over a three-year period. Researchers studying soil disturbances from prescribed burning found that water quality returned to pre-burn levels within two years when revegetation was incorporated. Without revegetation, water quality was depressed for four years before returning to pre-burn levels (Wright, Churchill, and

Stevens 1982). Nitrogen dissipated to control plot levels in four to five years after periodic burning of ponderosa pine forest (Covington and Sackett 1986).

Davis (1989) determined that nutrient changes occurring in a burned watershed corresponded with seasonal changes in an unburned control watershed. Nutrient concentrations were inversely related to the amount of snowmelt or precipitation that occurred (Johnson and Needham, 1966; Snyder, Haupt, and Belt 1975).

Slash burning showed on-site nutrient changes to be the most significant, with small concentrations of nutrients found downstream of the treated area, and insignificant increases between above and below sites (Snyder, Haupt, and Belt 1975). Variable results to water chemistry with slash burning were noted, but no significant effects were recorded (Stednick, Tripp, and McDonald 1982).

Richter, Ralston, and Harms (1982) demonstrated filtering of nutrients by litter and soil as a result of modest ash production. Wildfire caused little change in stream water quality, an effect attributed to the retention of nutrients in the upper soil layers (Johnson and Needham 1966; Grier 1975).

In a prescribed fire study of chaparral, the amount of total nutrients in unburned vegetation and litter was greater than the ash (DeBano and Conrad 1978). Minor increases in nutrients and pH occurred as a result of prescribed burning (Binkley et al. 1992).

Changes in soil nitrogen content through burning showed no detrimental effects. Repeated short interval burns maintained inorganic nitrogen concentrations greater than control plots (Covington and Sackett 1988).

Wildfires increased the concentration of inorganic forms of phosphorous. In contrast to wildfires, prescribed burning had little negative effect on phosphorous (Saa et al. 1993). Phosphorous concentrations were found to decrease over time in a

wildfire study (McColl and Grigal 1975; McColl and Grigal 1977). Greater concentrations of inorganic phosphorous occurred under canopied areas than uncanopied areas after wildfire (DeBano and Klopatek 1988).

HYPOTHESES

This evaluation of water quality effects from the management practice of prescribed burning in the General Creek Watershed tested the following hypotheses for nitrate, sulfate, phosphate, calcium, magnesium, and potassium:

Ho: There is no significant difference in nutrient concentrations between the treated (burned) and control (unburned) sample stations.

H_1: Nutrient concentrations between the treated (burned) and control (unburned) sample stations are significantly different.

Ho: There is no significant difference in nutrient concentrations between the above burn east (upstream) and the burn east (on-site) sample stations.

H_1: Nutrient concentrations between the above burn east (upstream) and the burn east (on-site) sample stations are significantly different.

Ho: There is no significant difference in nutrient concentrations between the burn east and the burn west sample stations.

H_1: Nutrient concentrations between the burn east sample stations and the burn west sample stations are significantly different.

Ho: There is no significant difference in phosphate and calcium concentrations between treated (burned) and control (unburned) sites.

H_1: Phosphate and calcium concentrations are significantly different between treated (burned) and control (untreated) sites.

METHODS

Study Sites

Lake Tahoe is located at an elevation of 1,898 m at 39° 6' north latitude and 120° 2' west longitude in the Sierra Nevada mountain range in the states of California and Nevada (Fig. 1). It covers an area of 501 km^2 (19 km wide and 35 km long) and has a maximum depth of 505 m, with a surrounding watershed of 812 km^2. Lake Tahoe is the third deepest inland lake in North America and tenth deepest worldwide (Jassby et al. 1994). It is renowned for its water clarity and low fertility, the result of its great depth, a small watershed to lake ratio, and an underlying granite parent material in the majority of the Lake Tahoe Basin.

General Creek is located in Sugar Pine Point State Park at 39° 3' north latitude and 120° 7' west longitude. The drainage area of the General Creek watershed is 11.9 square kilometers.

Weather patterns in the Lake Tahoe Basin may be localized due to variations in topography (Elliott-Fisk et al. 1996). Precipitation is distributed unequally within the Lake Tahoe Basin, with greater than 80 inches (203 cm) per year falling on the west side and 30 inches (76.1 cm) per year on the east side (United States Department of the Interior, Geological Survey 1999a). The majority of this precipitation occurs as snow. Winters generally occur between October and May. Occasional seasonal thunderstorms occurring from June through September produce small but locally intense amounts of rain.

This master's research project followed the protocol of a study conducted in the southeastern United States pine forest by Richter, Ralston, and Harms (1982) to evaluate prescribed fire effects which compared treated and control sub-watersheds. Two sub-watersheds located approximately one mile apart to the south of General

Creek within Sugar Pine Point State Park served as control and treatment sites within the larger General Creek watershed in the Lake Tahoe Basin (Appendix A). Four ephemeral tributaries to General Creek were sampled. Each ephemeral stream flowed with sufficient amounts of precipitation or snowmelt runoff for sampling. Runoff diminished within the watershed in June, 1997 as a result of ground water depletion and lack of sufficient precipitation to recharge the system.

Soils at the treated and control sites are of the Tallac gravelly coarse sandy loam (TcB) series. This soil series is typically glacial outwash deposit, located on 0-5 percent slopes. Runoff from spring snowmelt is shown to percolate only slightly into the soil surface and may accumulate above a weak clay layer (Rogers, 1974). A terminal moraine exists between the control east and control seep stations. This feature accounts for the rapid absorption and limited stream flow at the control east station and continued flow at the control seep station later into the season.

The California Department of Parks and Recreation conducted prescribed burns in the General Creek watershed in the fall of 1996. Burning occurred between September 23 and November 24, with a typical burn ranging from several days to a week in length. Burned areas were located within Sugar Pine Point State Park south of General Creek, and southwest of the park campground (Appendix A). In order to achieve burn prescriptions and provide for fire control and smoke management, plots were subdivided into smaller portions (Walter 1996). These plots covered an area of approximately 1.21 km in length and up to 0.40 km in width. This treatment area was the site for sample stations representative of the burned units.

Sampling

Data on surface water in the General Creek Watershed were collected for analysis between November 1996 and June 1997. Samples were collected during

periods of rainfall or snowmelt runoff. Runoff continued until June 1997, when streams became dry.

Six stations were sampled within the study area which was sub-divided into control and treatment sites. Control sample stations were located on the west side of the General Creek watershed. The control site was divided into east and west control units; the east portion contained two sampling stations and the west portion one sampling station. Relatively scant flow occurred along the east control tributary, although a downgradient seep was located. Samples for this stream were primarily collected from this seep. When sufficient upgradient flows occurred, samples were also collected from the upgradient station. The treatment site was located east of the control site. This site was similarly divided into east and west units. The east burn unit contained two sampling stations, upstream (unburned) and on-site of the treated area. No downstream sample station was established. One sample station was located in the west burn unit near the confluence of a tributary and General Creek.

Sampling stations remained the same throughout the sampling period. Each sample site was accessible during fair or adverse conditions, including snow cover. Access during warmer months was possible by foot or bicycle. Throughout months with snow cover, travel occurred by means of snowshoes or cross-country skis. Figure 2 illustrates typical winter site conditions.

Samples were collected using a grab sampling method during precipitation events and spring snowmelt. Analogous studies of water quality effects due to fire have used grab sampling from designated sites and were collected during runoff events (Stednick, Tripp, and McDonald 1982; Winzler and Kelly 1982). Individual sample volumes were contingent on the amount or duration of precipitation events, or length of snowmelt period, but equaled approximately 500 ml from each sampling station during

Figure 2. Typical winter site conditions at
General Creek watershed in Lake Tahoe, California

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a given sampling event. At least 20 rounds of sampling were conducted, for a total of approximately 20 samples from each sample station (total number of samples equals approximately 120). Airtight and leak-proof plastic Whirl-Pak© bags were used for water capture and storage (Fig. 3). Samples were placed on ice immediately and shipped directly to the USDA Forest Service Riverside Fire Laboratory for analysis.

Chemical Analysis

The Forest Service laboratory analyzed the water samples according to EPA protocols for the following constituents: phosphate, magnesium, calcium, nitrate, and sulfate. Ion chromotography was used to test for nitrates and sulfates, colormetric continuous flow analysis was conducted for phosphate, and an atomic absorption spectrophotometer was used to analyze samples for calcium, magnesium, and potassium.

Statistical Analysis

Water resource data is often non-normal in distribution and no assumptions were made regarding the distribution of nutrient concentrations from samples in this study. Data from this study were analyzed with Minitab®, a statistical software program. To determine distribution and general trends of data gathered in this study, initial examination of the data included plotting frequency distribution histograms. Normal probability plots, a parametric test procedure used to determine the normality of data, were also used (Helsel and Hirsch, 1992). The data from three of six constituents were normal and three showed distinct non-normal trends. Constituents with non-normal data included sulfate (SO_4^{-2}), magnesium (Mg^{+2}), and potassium (K^+). Data on nitrate (NO_3^-), phosphate (PO_4^{-2}), and calcium (Ca^{+2}) were approximately normal in distribution. Since non-normal characteristics were apparent with half of the nutrients

Figure 3. Whirl-Pak© bag used in streamwater sample collection at General Creek watershed in Lake Tahoe, California

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under observation in this study, non-parametric testing methods were used to analyze all data to ensure consistency in results.

Four sets of analyses were run using the Mann-Whitney U test to determine if statistical differences in sample distributions existed. Paired comparisons were made to detect changes in stream water nutrient concentrations as a result of burning. These comparisons included the east burn station and individual control sample stations, west burn station and individual control sample stations, east burn and west burn sample stations, and upstream (above burn east) and on-site sample stations at the burn east unit.

Calcium and phosphate concentrations were tested with the Pearson product moment correlation analyses to determine if a relationship existed between these constituents. This analysis is designed to indicate whether variability in either of these constituents is accounted for by variability in the other (Fowler and Cohen 1990).

Precipitation records from Sugar Pine Point State Park (Reinhardt 1997) and streamflow data from General Creek for water year 1996-1997 (United States Department of the Interior, Geological Survey 1999a) were compared with changes in constituent concentrations over time to determine potential effects of seasonal changes on nutrient loading.

RESULTS

Rainfall levels for the study period are shown in Table 1 and Figure 4. Above normal precipitation occurred in 1996 and 1997 during the first three months following the prescribed burn at this study site. Normal total precipitation as rain during these months is 10.8, 12.5, and 14.1 cm for November, December, and January, respectively. Rainfall increased by 10.2 cm in November, 34.6 cm in December, and 31.0 cm in January (Reinhardt 1997). This concentrated precipitation resulted in rain on snow events which produced early snowmelt and above average stream flows, which caused flooding throughout the Lake Tahoe Basin. Rainfall decreased to below normal amounts in subsequent months until June, 1997, when precipitation rose to 4.67 cm above normal (Reinhardt 1997). Previous dry conditions permitted rapid infiltration of this rain into the soil.

Local precipitation records and streamflow data from General Creek (United States Department of the Interior, Geological Survey 1999b) are given in Figures 4 and 5, respectively. Nutrient concentration values over time were measured. Descriptive statistics including maximum and minimum concentration values, and nutrient mean concentrations and standard deviations appear in Tables 2 and 3.

Table 2 lists maximum and minimum concentrations in milligrams per liter (mg/L) for constituents at all sampling stations. Nitrate concentrations were 0.01 to 2.12 mg/L at the burn east and burn west sample stations. The unburned above burn east sampling station ranged from 0.00 to 0.08 mg/L. Minimum and maximum values from the control stations were between 0.01 and 0.99 mg/L.

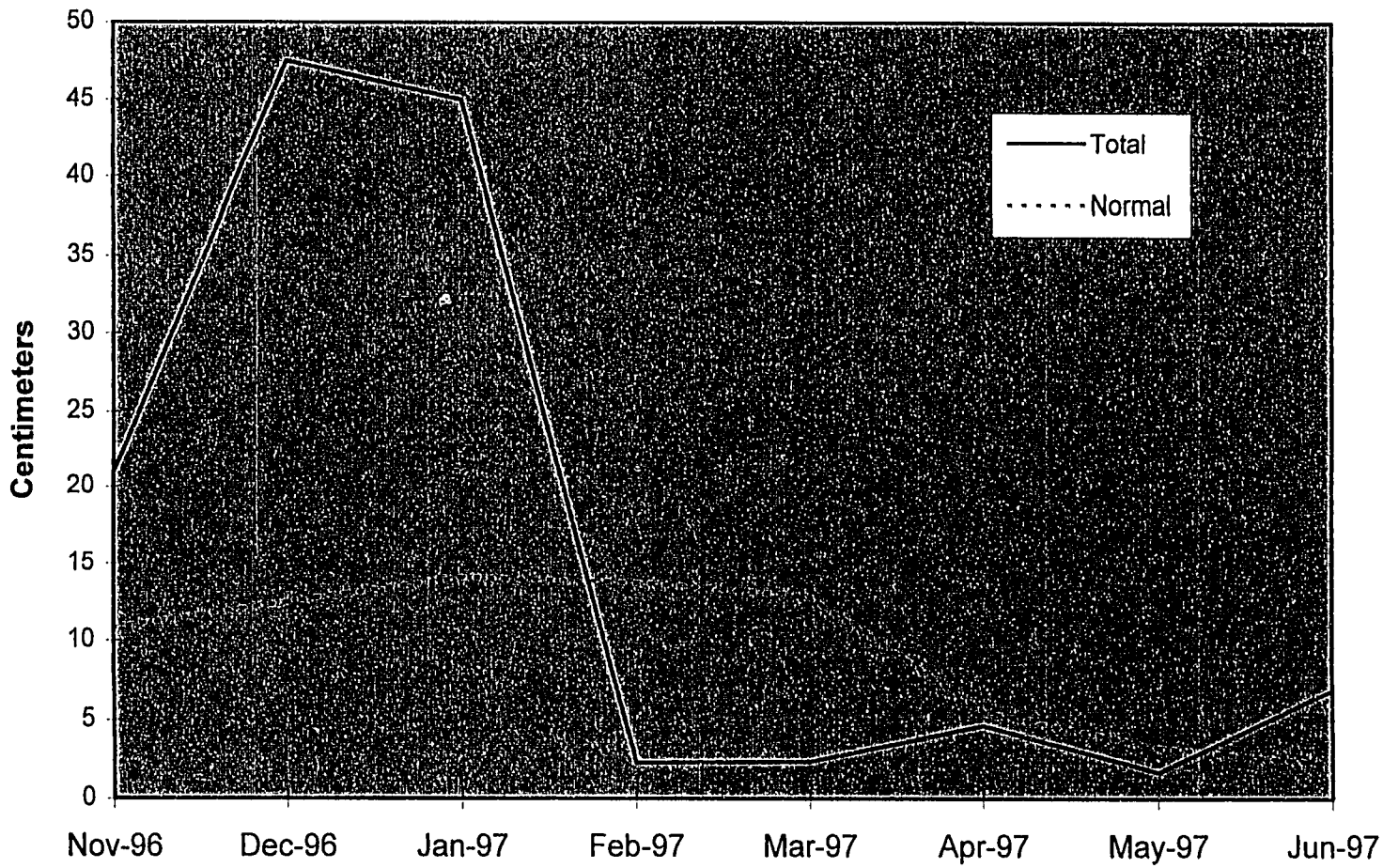
The burn stations showed SO_4^{-2} concentrations of 0.05 to 15.3 mg/L. Values from the above burn east sample station were between 0.049 and 0.10 mg/L. Control station SO_4^{-2} values ranged from 0.0 to 0.72 mg/L.

Table 1. Precipitation as rain for November 1996 - June 1997 at Sugar Pine Point State Park. Measurements are in inches. Data source: Reinhardt 1997.

Month	Current Monthly Total	Normal Monthly Total	Record High
November	8.28	4.26	14.8
December	18.7	4.93	18.7
January	17.7	5.56	17.7
February	1.05	5.42	19.3
March	0.92	5.06	17.4
April	1.83	2.17	7.35
May	0.66	1.28	4.49
June	2.70	0.86	2.70

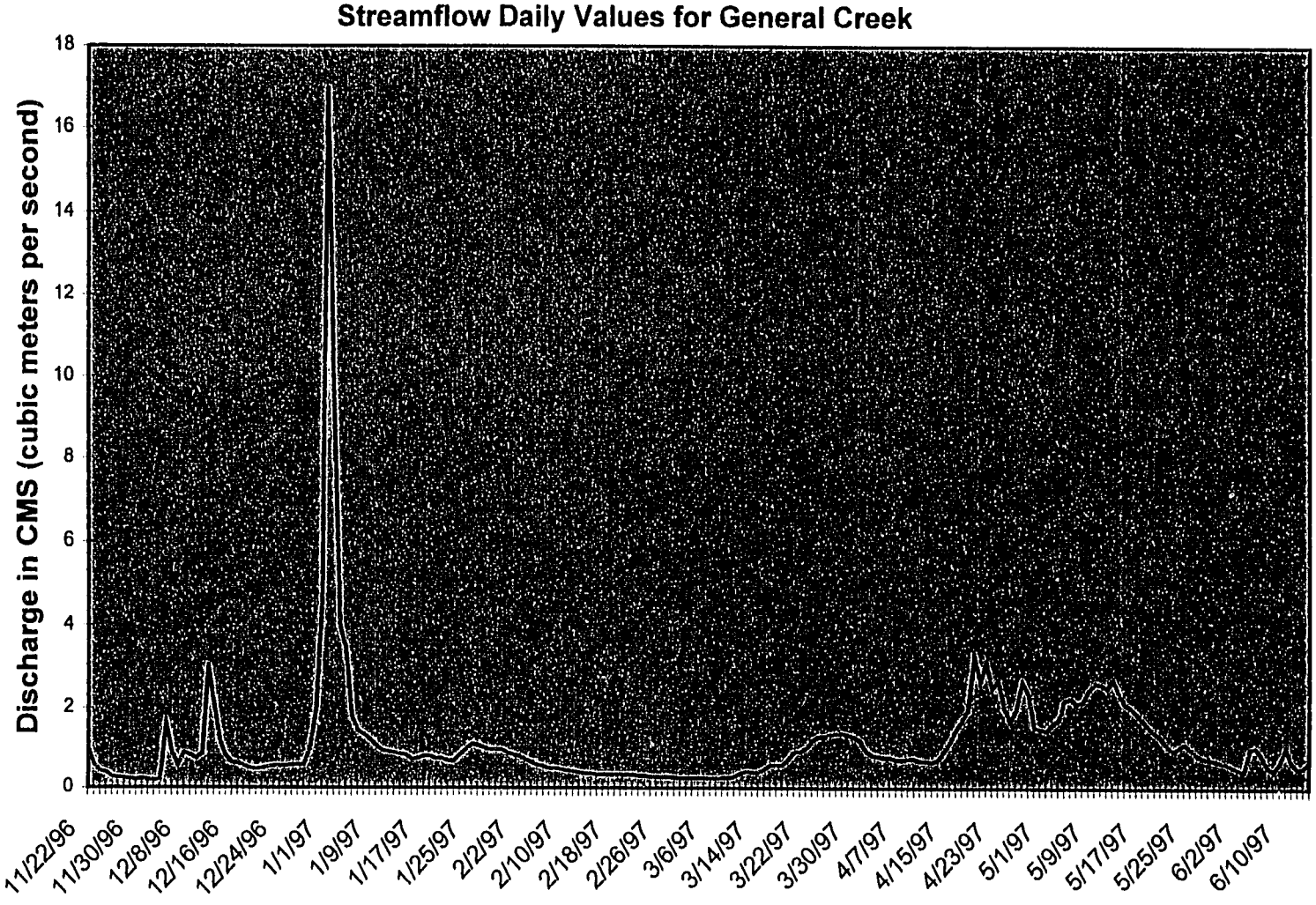
Figure 4

Rainfall Precipitation Sugar Pine Point State Park



Source: Reinhardt, T. 1997. Sugar Pine Point State Park Precipitation Record.

Figure 5



Source: USDI Geologic Survey. 1999. Historical Streamflow Daily Values for General Creek.

Table 2. Maximum and minimum values recorded for anions and cations at each sampling station. Concentrations are in mg/L.

Sample Station	**Anion**			**Cation**		
	NO_3^-	SO_4^{-2}	PO_4^{-2}	Ca^{+2}	Mg^{+2}	K^+
Burn Unit						
Burn East n=20						
Maximum	0.29	1.02	0.22	5.39	0.41	0.84
Minimum	0.0	0.0	0.0	0.99	0.13	0.28
Burn West n=19						
Maximum	2.12	15.3	0.19	10.3	1.22	1.69
Minimum	0.0	0.12	0.0	1.29	0.14	0.37
Above Burn East (unburned) n=11						
Maximum	0.08	0.16	0.13	8.56	0.58	0.45
Minimum	0.0	0.0	0.0	1.90	0.29	0.30
Control Unit						
Control East n=12						
Maximum	0.77	0.93	0.17	6.28	3.27	0.66
Minimum	0.0	0.0	0.0	1.08	0.12	0.30
Control West n=16						
Maximum	0.91	0.72	0.18	5.81	0.69	0.85
Minimum	0.0	0.28	0.0	0.60	0.11	0.19
Control Seep n=17						
Maximum	0.99	0.72	0.17	7.98	0.37	0.54
Minimum	0.0	0.0	0.01	0.80	0.05	0.16

Table 3. Mean concentrations and standard deviations for anions and cations at each sampling station. Concentrations are in mg/L.

Sample Station	Anion			Cation		
	NO_3^-	SO_4^{-2}	PO_4^{-2}	Ca^{+2}	Mg^{+2}	K^+
Burn Unit						
Burn East n=20	0.03±0.07	0.35±0.30	0.06±0.06	2.22±0.91	0.31±0.70	0.45±0.17
Burn West n=19	0.38±0.48	5.2±5.92	0.07±0.06	5.03±2.76	0.51±0.25	0.73±0.35
Above Burn East (unburned) n=11	0.01±0.03	0.06±0.06	0.05±0.04	4.02±2.87	0.36±0.09	0.40±0.04
Control Unit						
Control East n=12	0.25±0.32	0.27±0.22	0.07±0.06	2.10±1.53	0.41±0.90	0.44±0.12
Control West n=16	0.17±0.28	0.19±0.22	0.05±0.06	2.35±1.45	0.37±0.13	0.56±0.18
Control Seep n=17	0.31±0.28	0.29±0.16	0.04±0.04	2.71±1.62	0.19±0.07	0.36±0.08

Phosphate minimum and maximum values at the east and west burn stations were 0.0 to 0.22 mg/L. Above burn east sample station values ranged between 0.0 to 0.06 mg/L. Control station values of PO_4^{-2} were 0.01 to 5.60 mg/L.

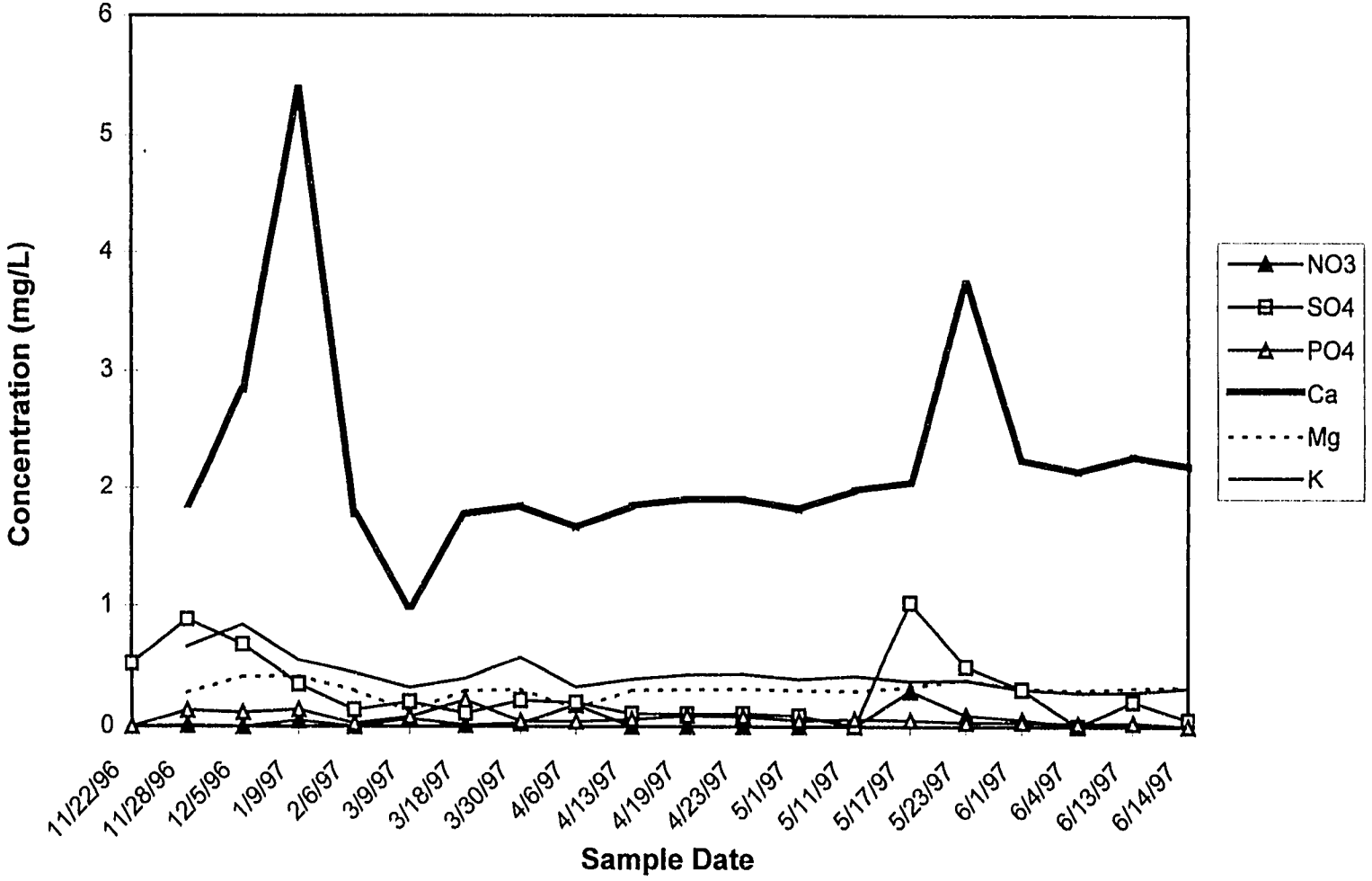
Concentration values for Ca^{+2} at the burn stations ranged from 0.99 to 10.34 mg/L. Concentrations of 2.12 to 8.56 mg/L occurred at the above burn east sample station. Values for Ca^{+2} at the control stations were between 0.32 and 7.98 mg/L. Although the maximum and minimum concentrations were lower at the control stations, values were not consistently lower at these sites (Table 2).

Magnesium values for the burn stations ranged between 0.13 and 1.22 mg/L. Concentration values at the above burn east sample station were 0.29 to 0.38 mg/L. Control stations showed a low and high value for Mg^{+2} of 0.05 to 3.27 mg/L, respectively.

The concentration values of K^+ at the east and west burn stations were between 0.28 and 1.69 mg/L. The above burn east sample station values ranged between 0.30 and 0.45 mg/L. Potassium concentration values at the control stations showed minimum and maximum concentration values of 0.16 and 0.85 mg/L, respectively.

Concentrations of the six tested ions for the east burn station are shown in Figure 6. The burn east station demonstrated high Ca^{+2} concentrations over time. A decrease in all nutrient concentrations with the exception of NO_3^- (March 9) was exhibited. This decrease occurred with rising temperatures and a period between rain events. A small increase in NO_3^- and SO_4^{-2} concentrations corresponded with a decrease of cations at this site which accompanied reduced streamflows (April 6). Cations increased and decreased at similar times, with the exception of a few high Ca^{+2} values (January 9 and May 23). These peaks of Ca^{+2} corresponded with high streamflow from rain on snow events or spring snowmelt runoff. At the end of the

Figure 6
Burn East Sampling Station
Nutrient Concentrations



sampling period (June 14, 1997), PO_4^{-2} concentrations returned to the level noted at the onset of sampling at this station (November 22, 1996). Nitrate and SO_4^{-2} values were also noted to decrease at the end of the sampling period.

The burn west station showed frequent fluctuations of nutrient concentrations during the sampling period (Fig. 7). Calcium also showed high concentrations at this station. Calcium and SO_4^{-2} exhibited a few extreme values. Sulfate showed increased concentrations at this site for the first two months following burning. A peak in all cation concentrations corresponded with 3.0 inches of rainfall on December 5. A notable decrease in all cation and SO_4^{-2} concentrations followed a month later (January 9). This decrease was preceded by flooding events. Decreases in most nutrient concentrations were exhibited shortly after a peak in streamflow occurred on February 6, March 9, and April 6. Lack of precipitation for at least 5 days preceded each of these sample dates. A rise in all nutrient concentrations with the exception of PO_4^{-2} occurred numerous times during the sampling period which corresponded with peak runoff (March 30, April 13, May 11, and May 23).

Higher anion and cation concentrations were exhibited at the burn west station and were generally higher than the burn east station, with more fluctuation in nutrient concentration overall. Nutrient concentrations at the burn west station were 2-16 times greater than the burn east station throughout the study. However, these sites showed similar trends of nutrient increase and decrease. Comparable nutrient behavior was noted on a few occasions, and coincided with increased streamflow (March 30).

Mean concentrations of constituents for the burn unit sample stations appear in Figure 8 and Table 3, and include the unburned upstream (above burn east) station. The burn west station displayed greater mean concentrations of all constituents. Mean Ca^{+2} concentration was approximately two times higher at the burn west than the burn

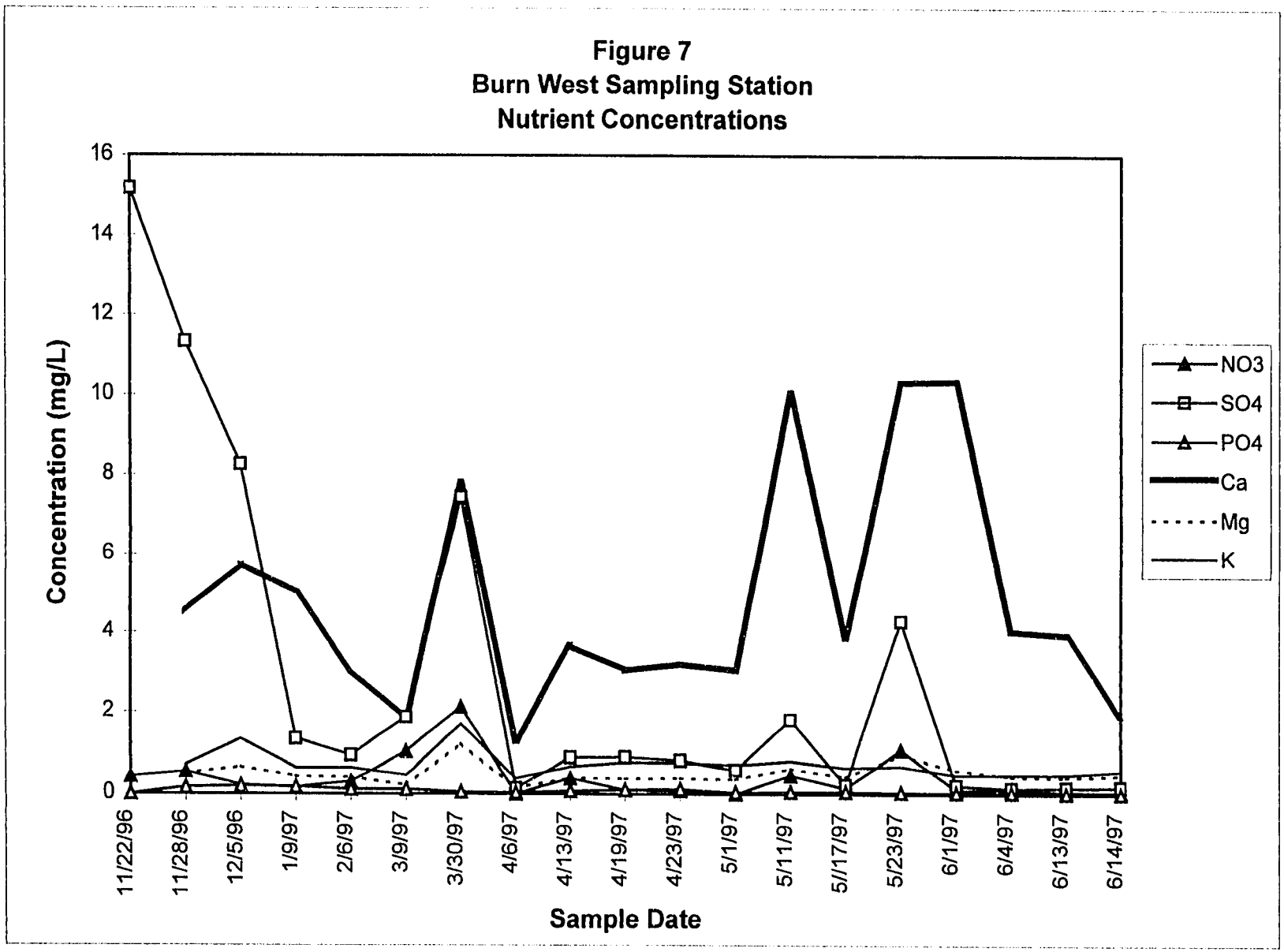
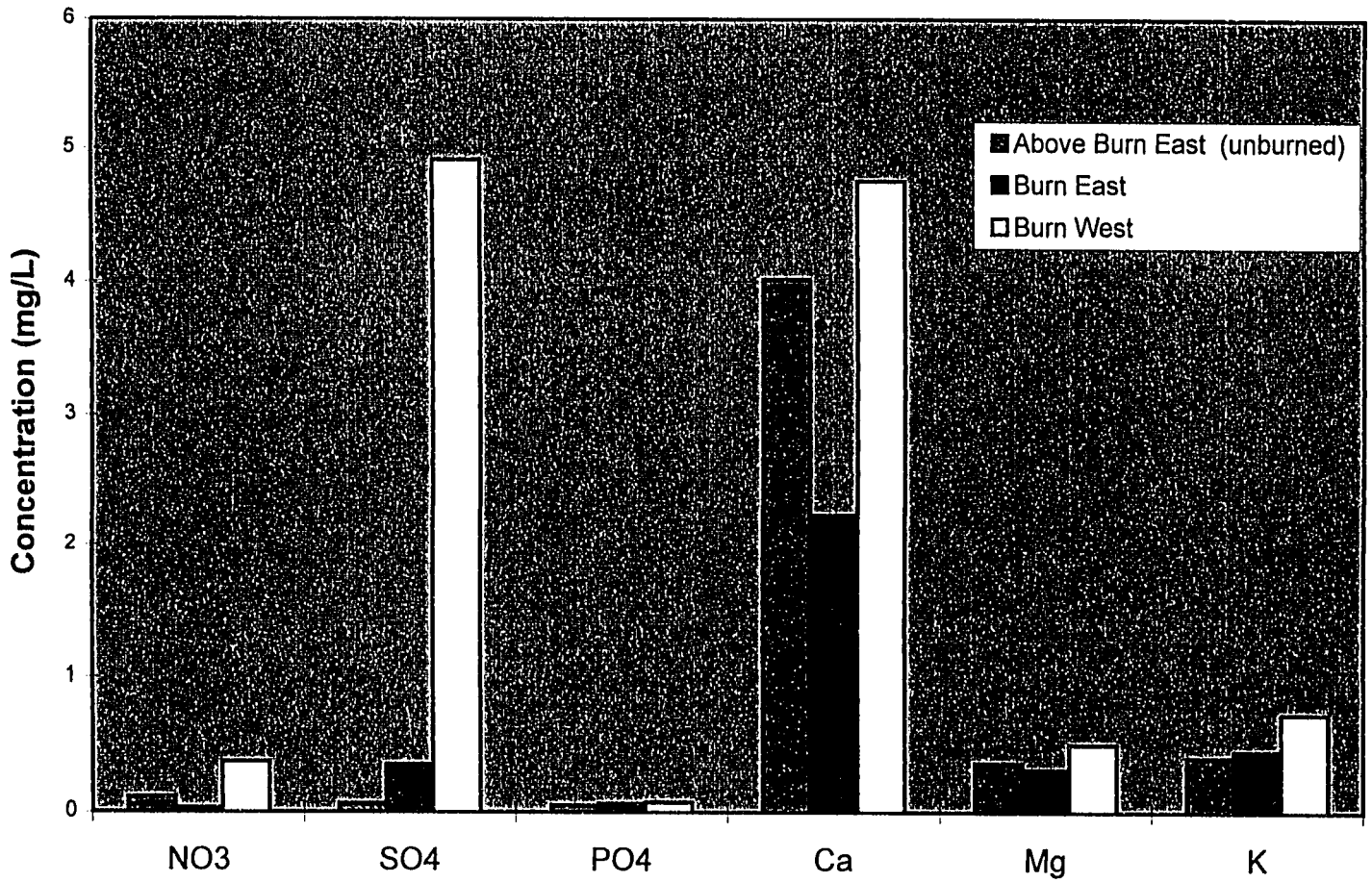


Figure 7
Burn West Sampling Station
Nutrient Concentrations
Concentration (mg/L)
16
14
12
10
8
6
4
2
0
11/22/96
11/28/96
12/5/96
1/9/97
2/6/97
3/9/97
3/30/97
4/6/97
4/13/97
4/19/97
4/23/97
5/1/97
5/11/97
5/17/97
5/23/97
6/1/97
6/4/97
6/13/97
6/14/97
Sample Date
NO3
SO4
PO4
Ca
Mg
K

Figure 8
Mean Nutrient Concentrations for
Above Burn East, Burn East, and Burn West Sample Stations



east station, and was greater than all other sampling stations. Statistical analysis using the Mann-Whitney U test showed significant differences at the 95% confidence level in nutrient concentrations between the burn east and burn west stations, with the exception of PO_4^{-2}. Phosphate concentrations were not statistically different at these sample stations.

The mean Ca^{+2} concentration at the unburned upstream (above burn east) station was between the burn west station and burn east station mean concentrations. The mean concentration of PO_4^{-2} at the upstream (above burn east) station was comparable to burn east and burn west means. The Mann-Whitney U test (at the 95% confidence level) was used to determine significant differences between burned and unburned areas with the same site conditions (burn east and above burn east). No significant difference in concentrations of NO_3^-, PO_4^{-2}, Mg^{+2}, or K^+ between these sites occurred. Sulfate concentration was significantly greater at the burn east station than the upstream (above burn east) station. Calcium showed opposite results; the upstream (above burn east) sample concentrations were significantly greater than the burn east sample concentrations.

Calcium showed high concentrations over time at the control east station (Fig. 9). A single spike in Mg^{+2} concentration occurred on January 9. NO_3^-, SO_4^{-2}, PO_4^{-2}, and K^+ displayed similar concentrations throughout the study. Nitrate and SO_4^{-2} also demonstrated similar trends, and showed increased concentrations on a few occasions. All constituents with the exception of PO_4^{-2} increased on April 6 with streamflow increases.

Calcium concentrations at the control west station were also high. Magnesium and K^+ concentrations were low during the first two sample collections. Anions at the

Figure 9
Control East Sample Station Nutrient Concentrations

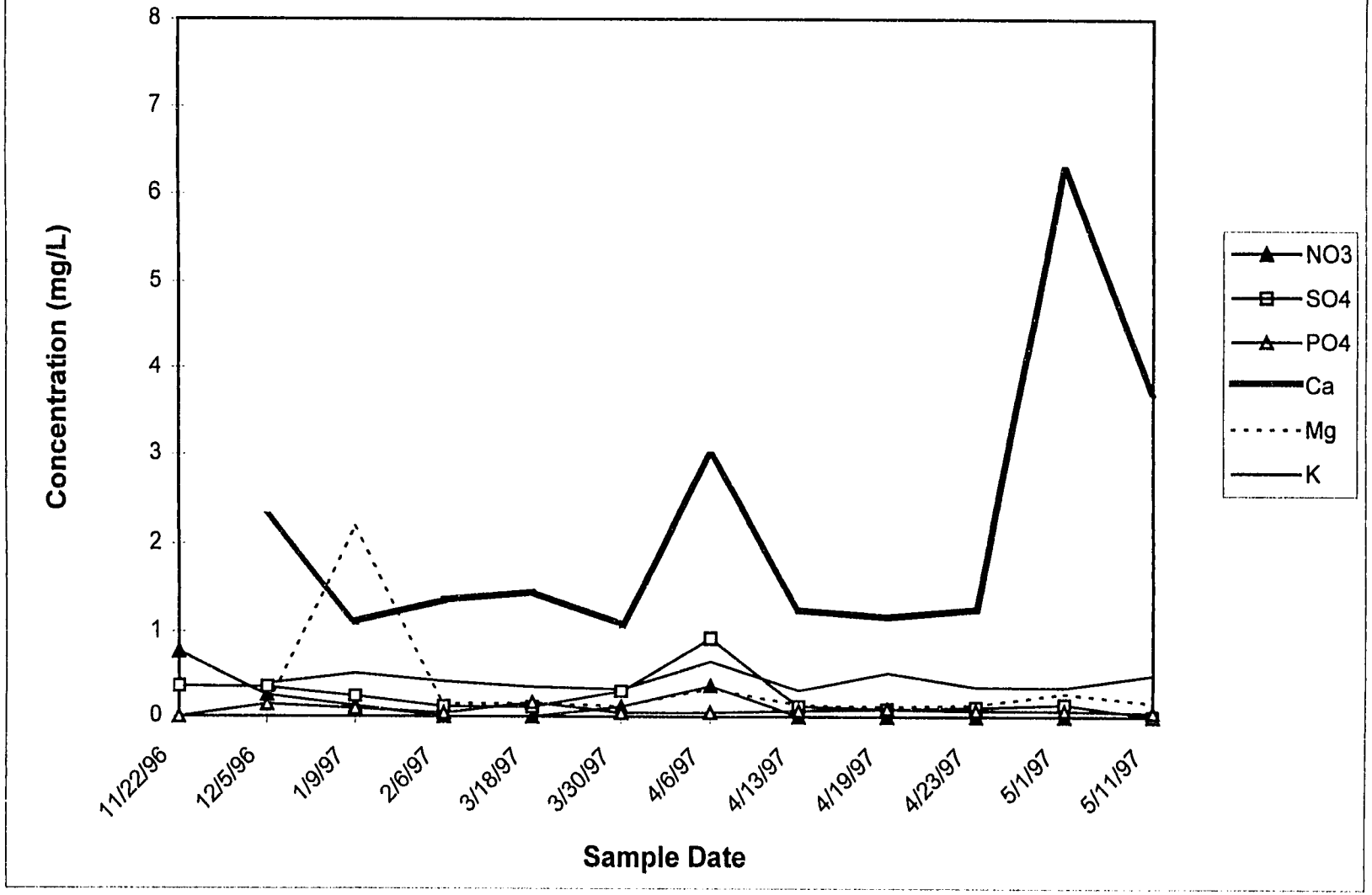
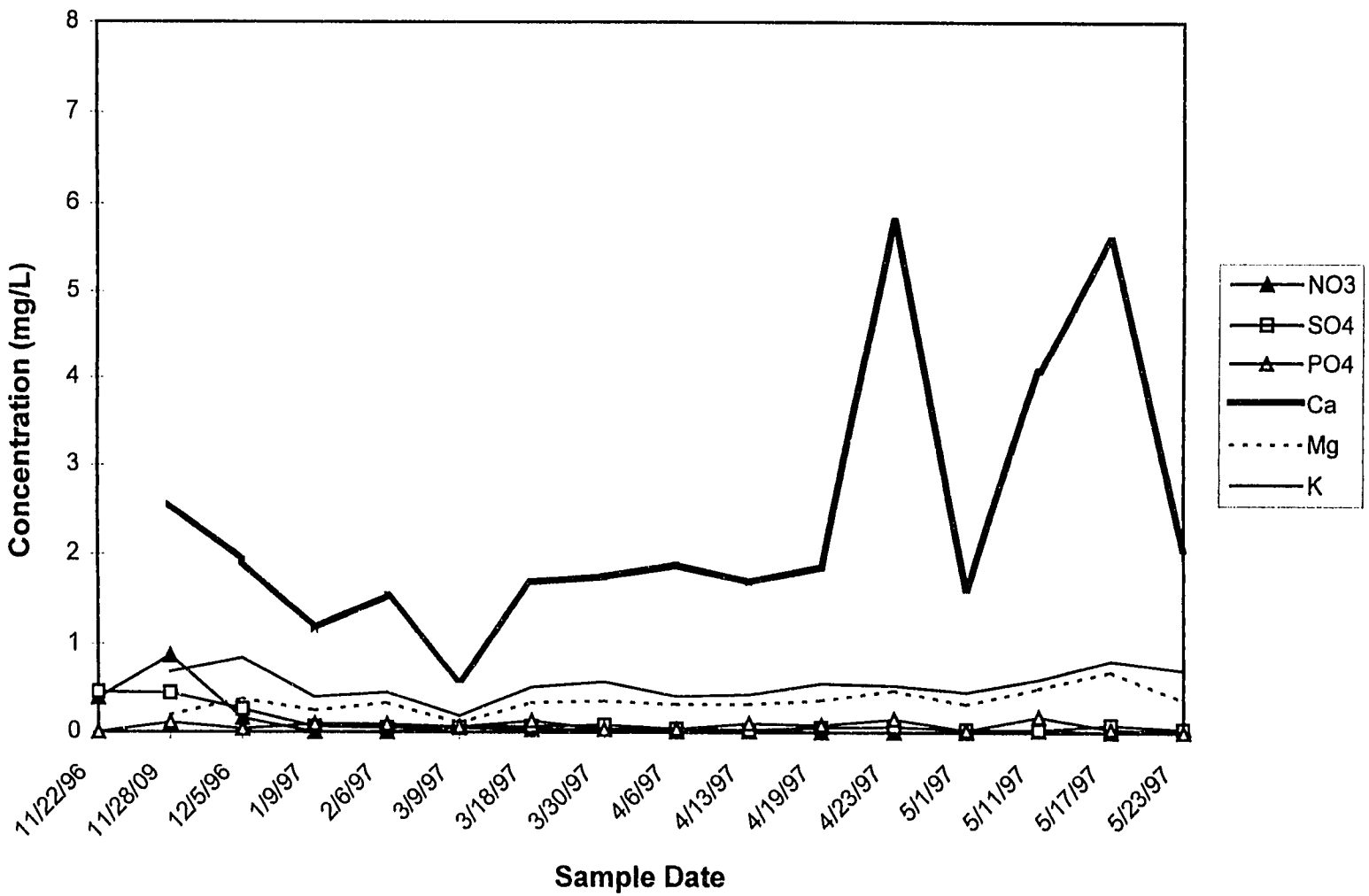


Figure 10
Control West Sample Station Nutrient Concentrations



control west station demonstrated fluctuating low concentrations (Fig. 10), although a few higher values were noted at the beginning of the study. Magnesium and K^+ followed the same trend in concentration changes as Ca^{+2} during most of the study. Cation concentrations decreased considerably on three occasions (January 9, March 9 and May 1). These decreases occurred after a large flood event, a period of reduced streamflow, and a snowmelt runoff event.

At the control seep station, Ca^{+2} again showed large concentrations and exhibited large fluctuations in concentration during the sampling period (Fig. 11). The remaining nutrients demonstrated low concentrations throughout the study. Small increases and decreases were noted in these nutrients.

Burn and control unit mean concentrations are shown in Figure 8 and 12, respectively. Mean concentrations for all constituents are also shown in Table 3. The burn west station demonstrated a mean Ca^{+2} concentration value two times greater than the highest control mean concentration. Phosphate means corresponded closely between all stations. The burn west mean concentration of SO_4^{-2} was greater than all other burn or control station means. The control stations exhibited greater mean NO_3^- concentrations of 0.17, 0.25, and 0.31 mg/L, compared to the burn east station mean concentration of 0.03 mg/L (Table 3).

Combined means for each constituent at the three control sites and two burned sites show the overall mean for each ion at this study site. These results appear in Figure 13, which shows noticeably greater means of SO_4^{-2}, PO_4^{-2}, and Ca^{+2}, Mg^{+2}, and K^+ at burn stations than at control stations.

Individual burn and control stations were tested with the Mann-Whitney U test (at a 95% confidence level) to determine the differences in nutrient concentrations between each sample station. The burn east station had significantly lower

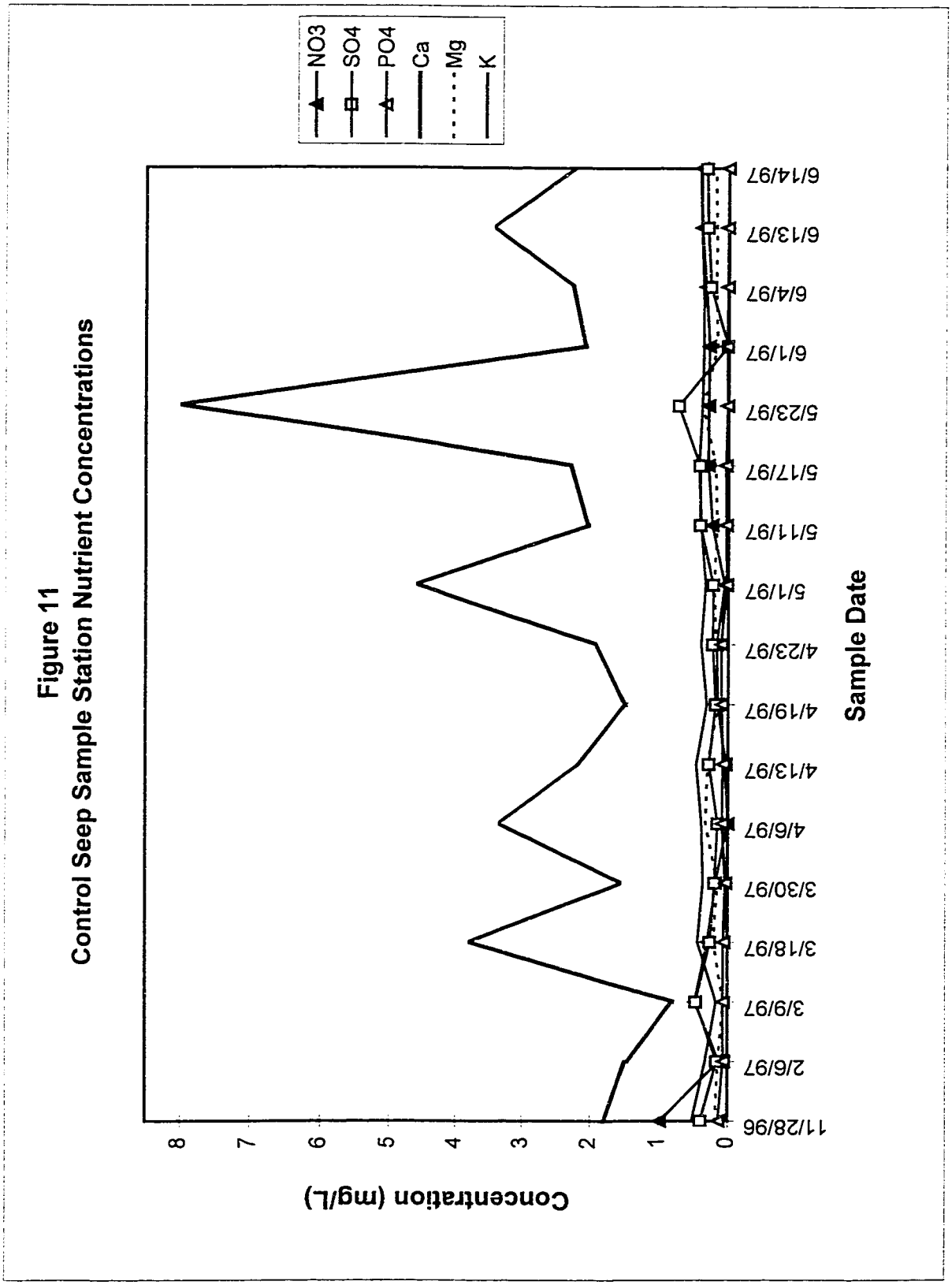


Figure 11
Control Seep Sample Station Nutrient Concentrations
NO3
SO4
PO4
Ca
Mg
K
Concentration (mg/L)
0
1
2
3
4
5
6
7
8
11/28/96
2/6/97
3/9/97
3/18/97
3/30/97
4/6/97
4/13/97
4/19/97
4/23/97
5/1/97
5/11/97
5/17/97
5/23/97
6/1/97
6/4/97
6/13/97
6/14/97
Sample Date

Figure 12
Mean Nutrient Concentrations for
Control Seep, Control East, and Control West Sample Stations

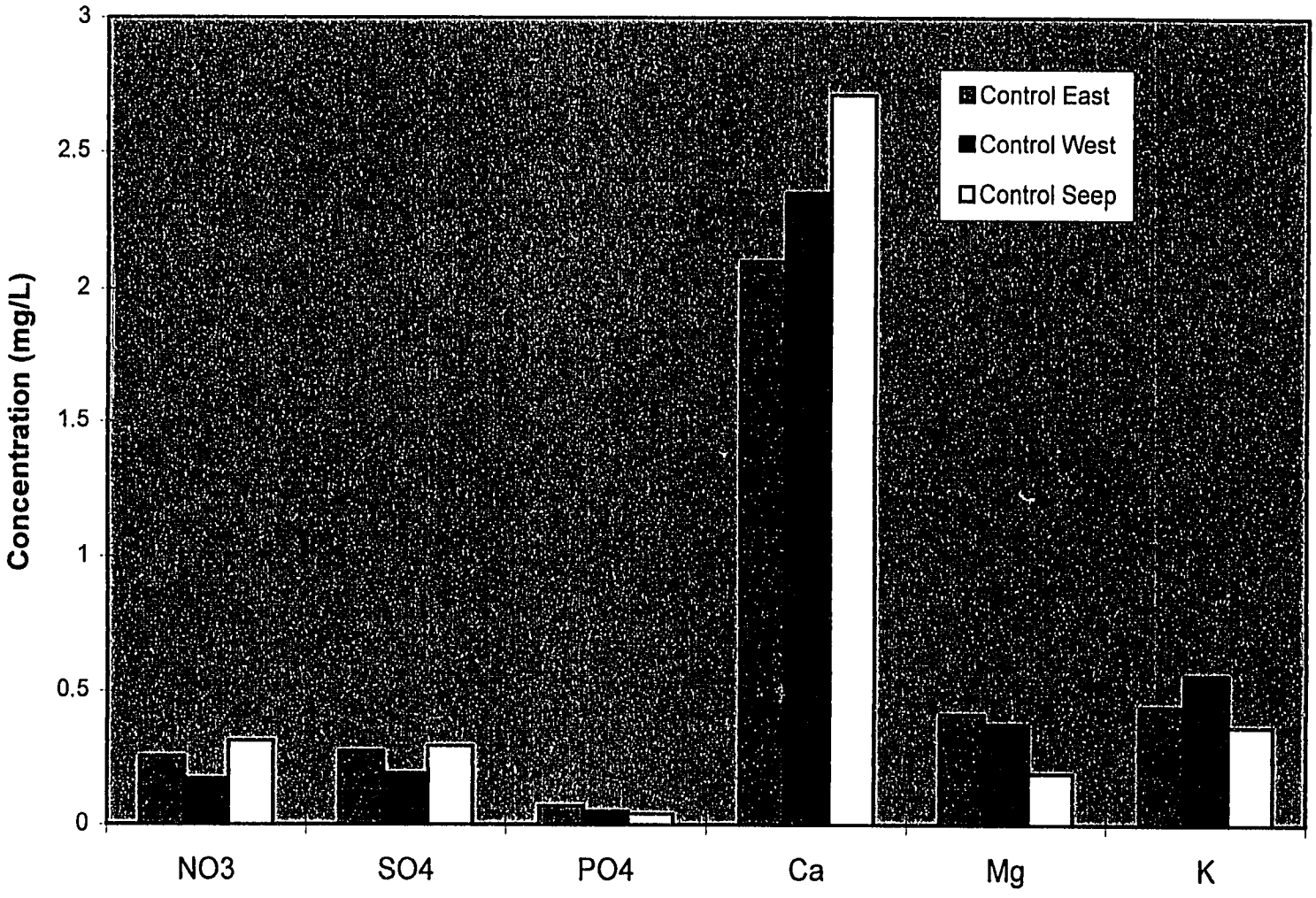
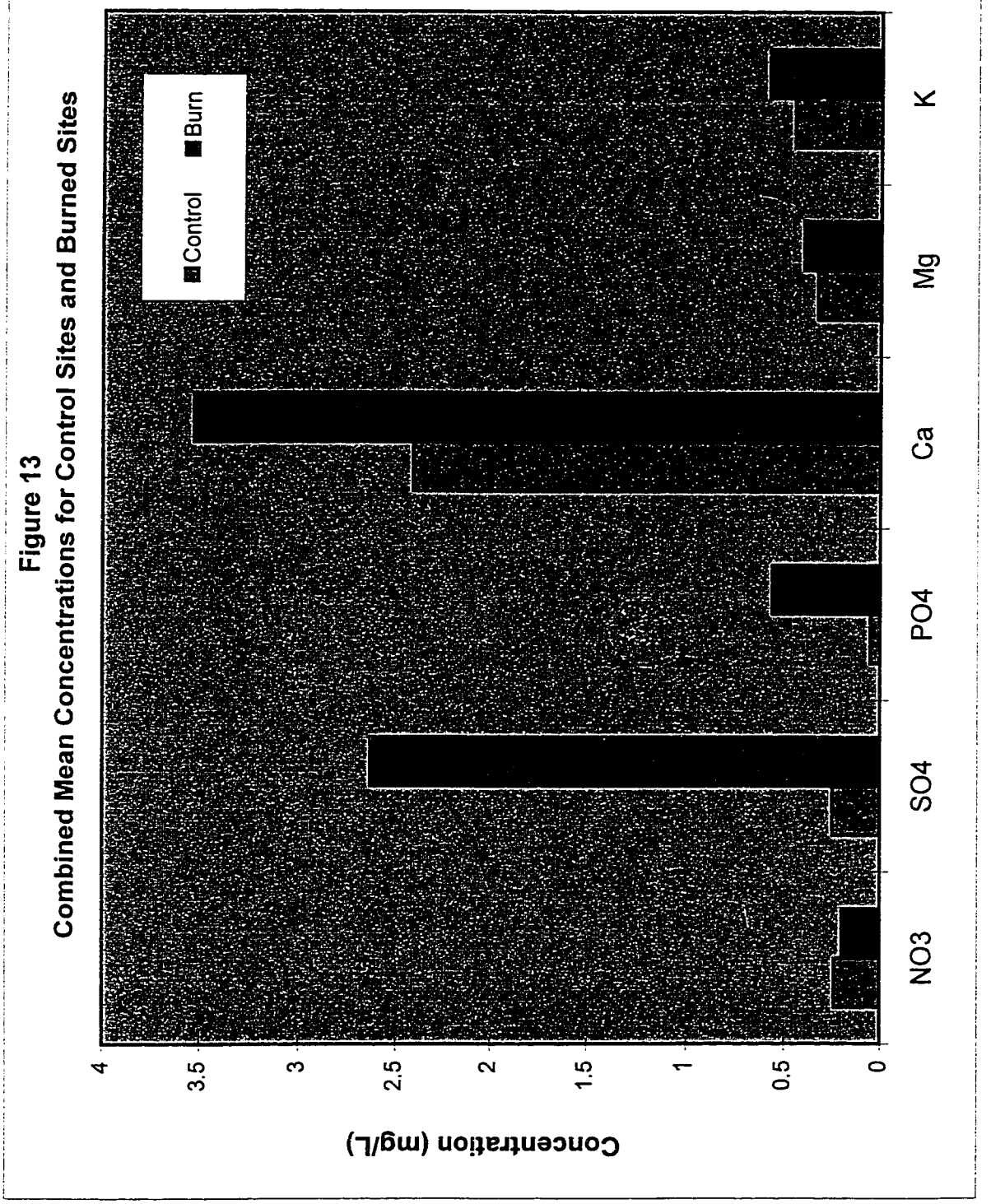


Figure 13
Combined Mean Concentrations for Control Sites and Burned Sites



concentrations of NO_3^- than each control station, while the burn west station showed significantly greater NO_3^- differences compared to the control west station. Phosphate mean concentrations showed minor differences between the burn and control units. Statistical test results confirmed these observations. Although small mean differences were shown between burn and control stations, the control east station had statistically greater PO_4^{-2} concentration than the burn east or burn west stations. Other control stations showed no significant differences in PO_4^{-2} concentration between the burn east or burn west stations. Calcium, Mg^{+2}, and K^+ showed significantly greater concentrations at the burn stations compared to the control stations.

Phosphate and Ca^{+2} were observed for interactions stimulated by burning. Mean concentrations for PO_4^{-2} and Ca^{+2} are shown in Figure 14. Increases and decreases in concentration followed the same pattern for about half of the samples at the control stations (Fig. 15, 16, and 17). Similar trends were exhibited between Ca^{+2} and PO_4^{-2} at the burn east station until later in the study (May 17), when PO_4^{-2} concentration dropped off considerably (Fig. 18). A comparable outcome was exhibited at the burn west station (Fig. 19). Using the Pearson product moment correlation analysis, a relatively weak relationship between Ca^{+2} and PO_4^{-2} was found at this study site. Weak to very weak negative correlations were exhibited by the burn west (-0.1), control east (-0.16), and control seep (-0.33) sample stations. Positive correlations from very weak to strong occurred with Ca^{+2} and PO_4^{-2} at the burn east (0.165), control west (0.347), and upstream (above burn east) (0.794) stations.

Figure 14

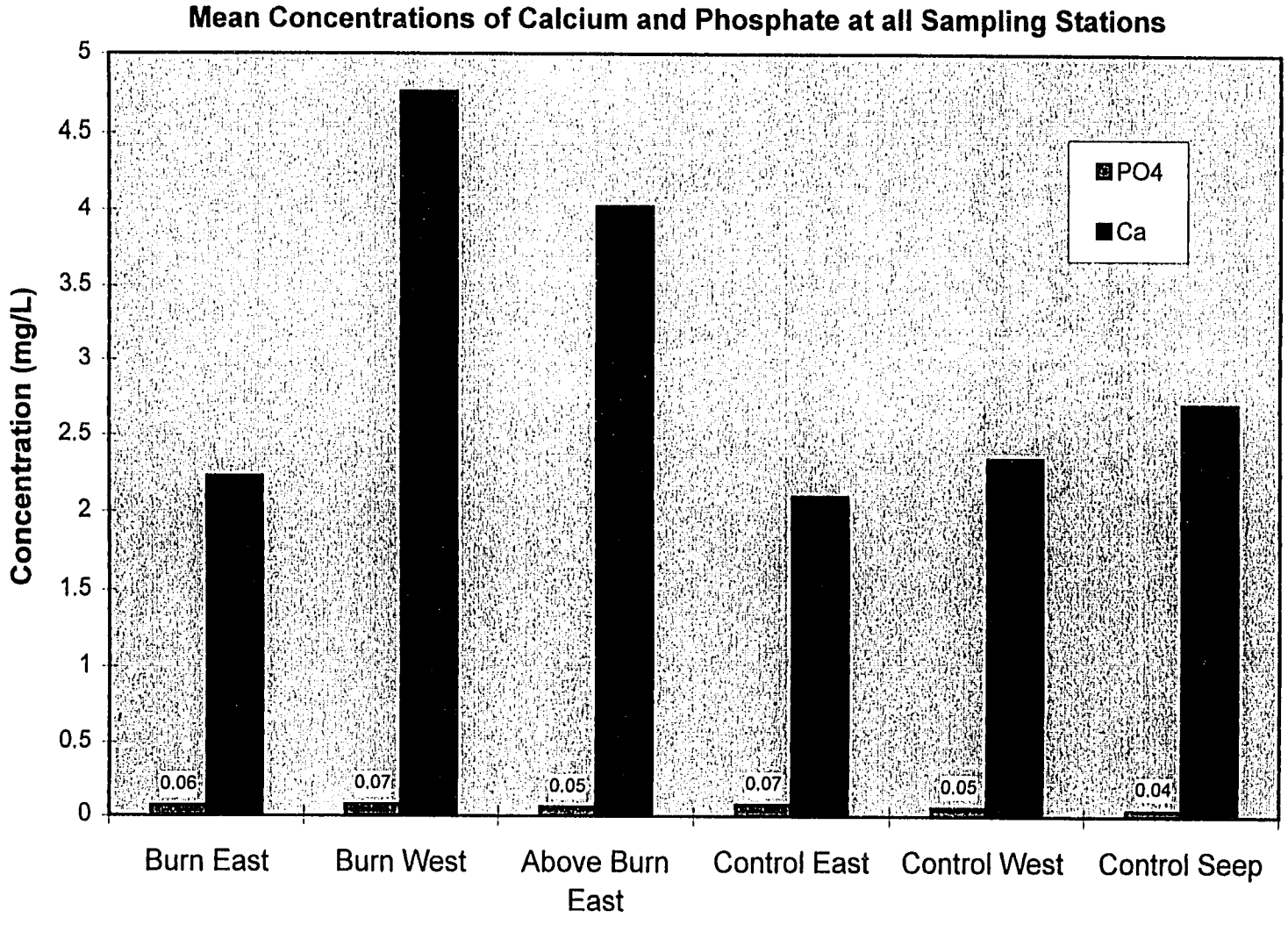

Mean Concentrations of Calcium and Phosphate at all Sampling Stations
Concentration (mg/L)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
PO4
Ca
0.06
0.07
0.05
0.07
0.05
0.04
Burn East
Burn West
Above Burn East
Control East
Control West
Control Seep

Figure 15
Control West Sample Station
Calcium vs. Phosphate Concentrations

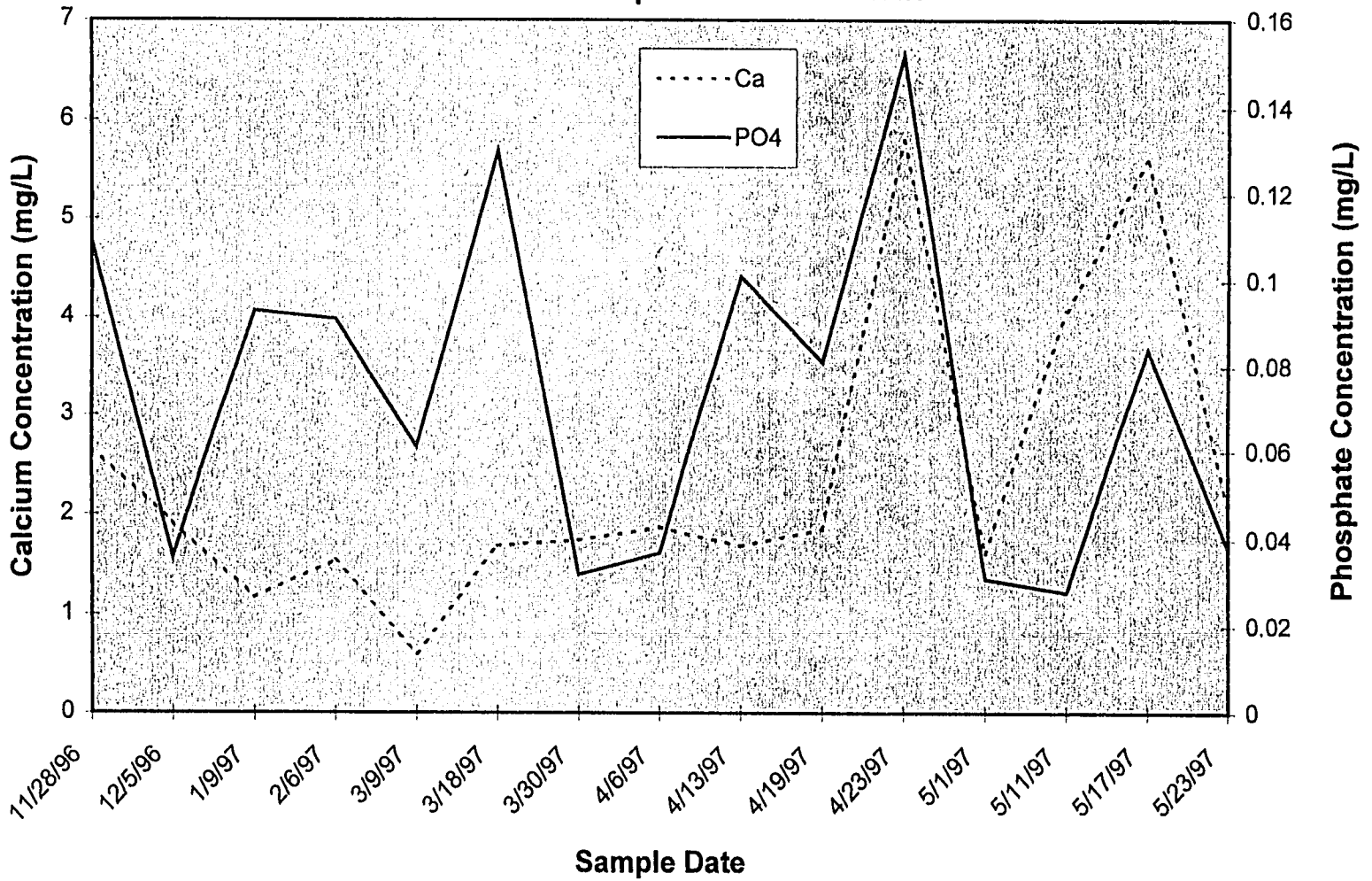


Figure 16
Control Seep Sample Station
Calcium vs. Phosphate Concentrations

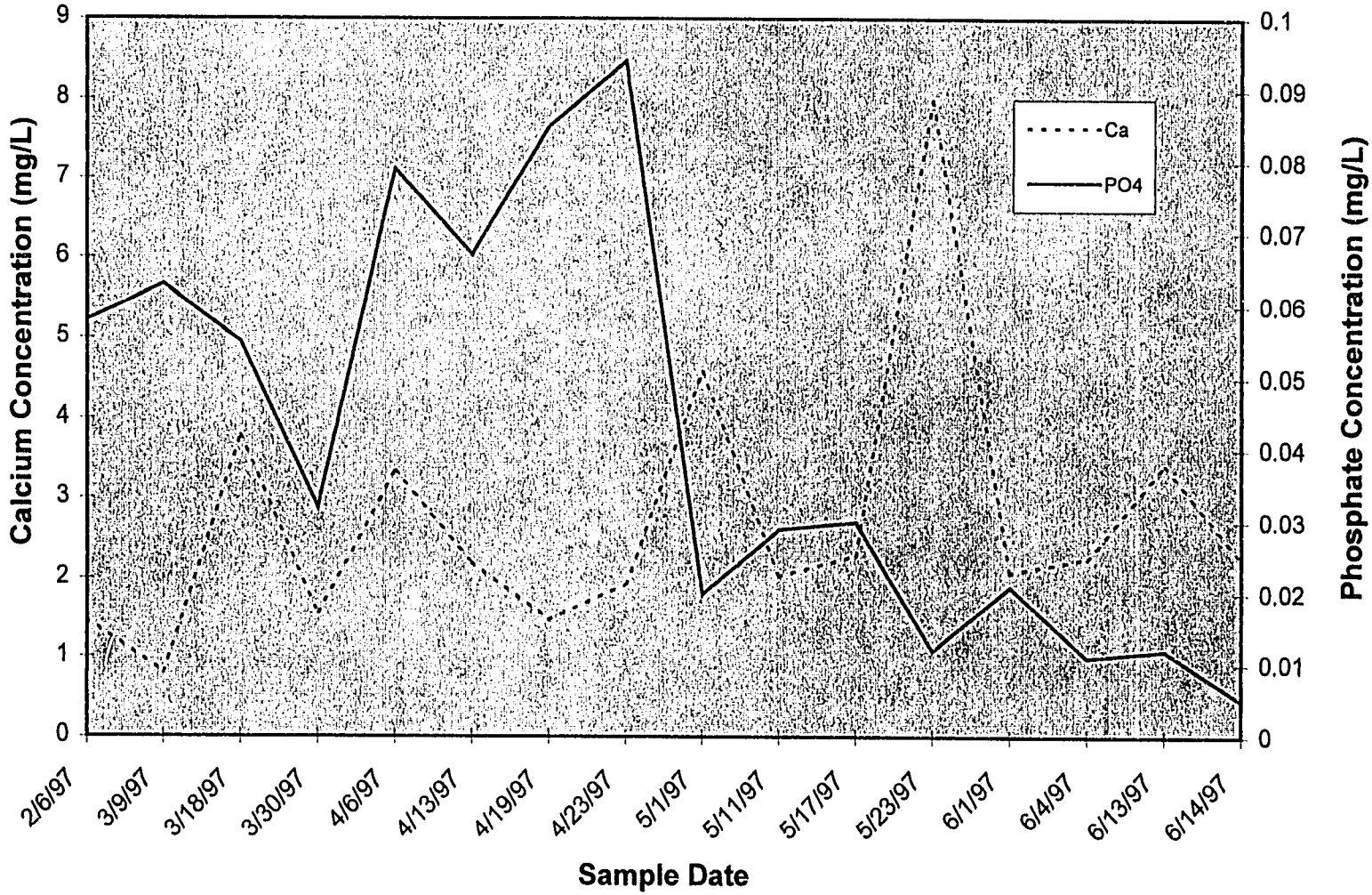


Figure 17
Control East Sample Station
Calcium vs. PO4 Concentration

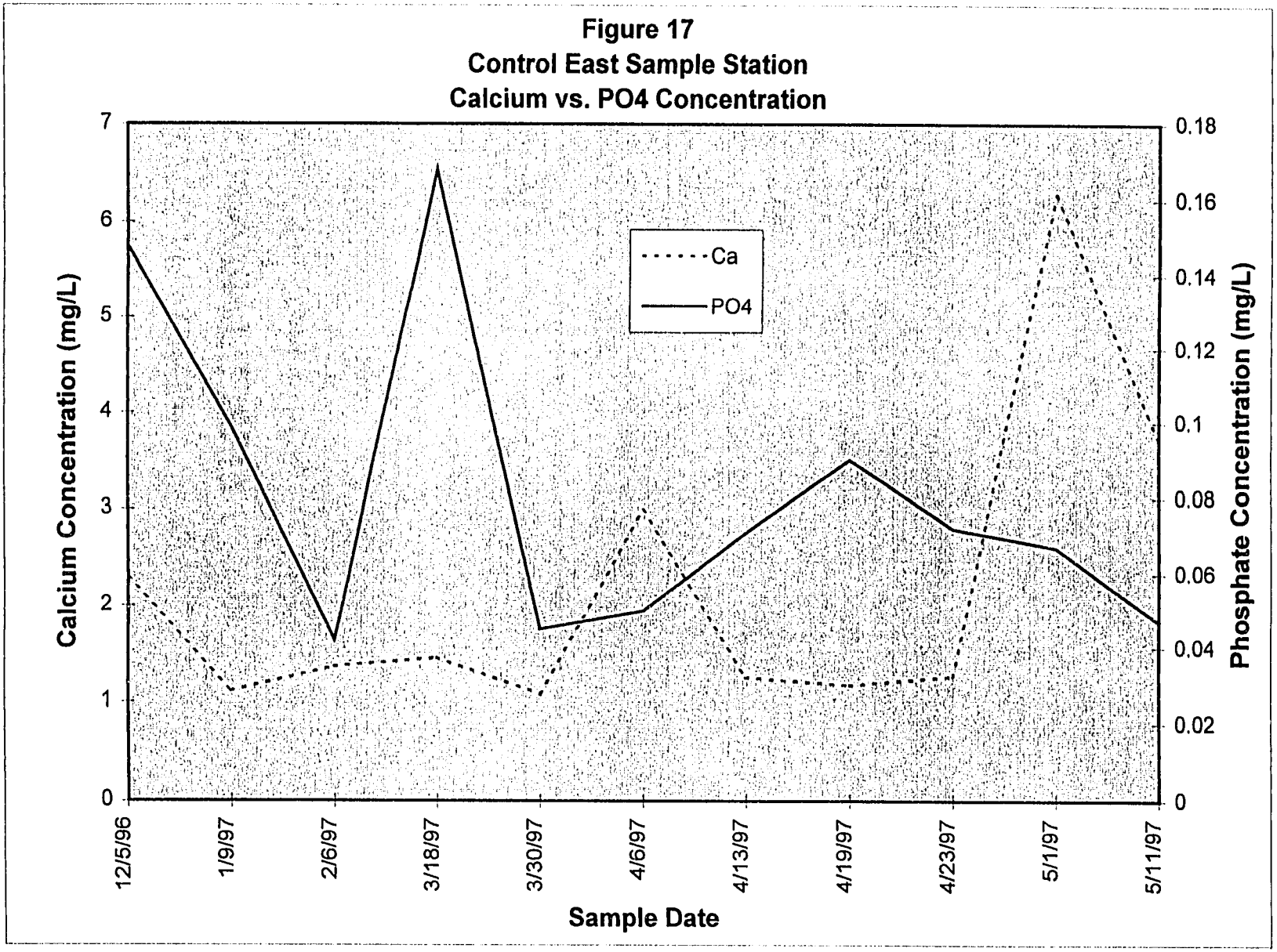


Figure 18
Burn East Sample Station
Calcium vs. Phosphate Concentrations

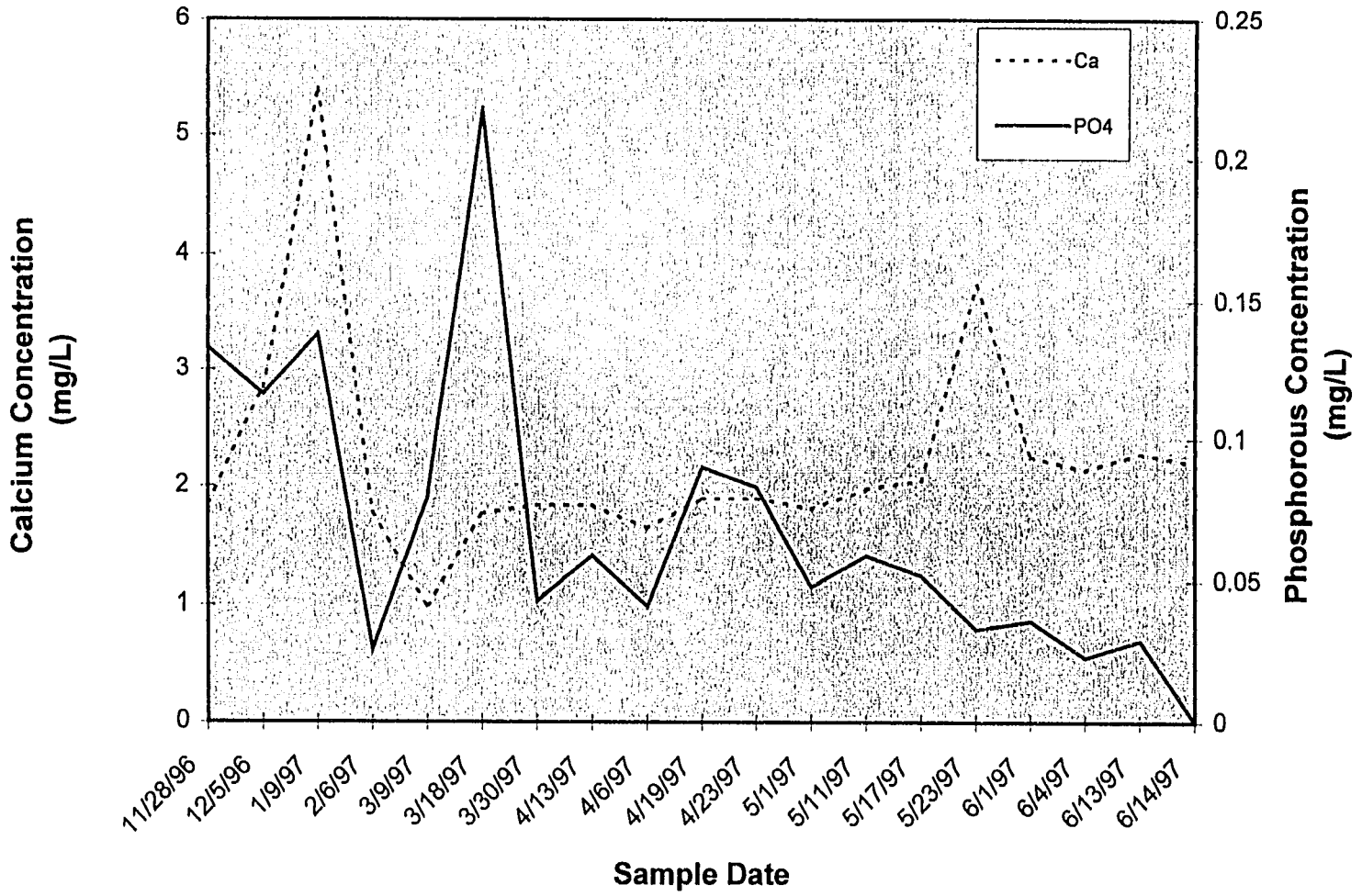
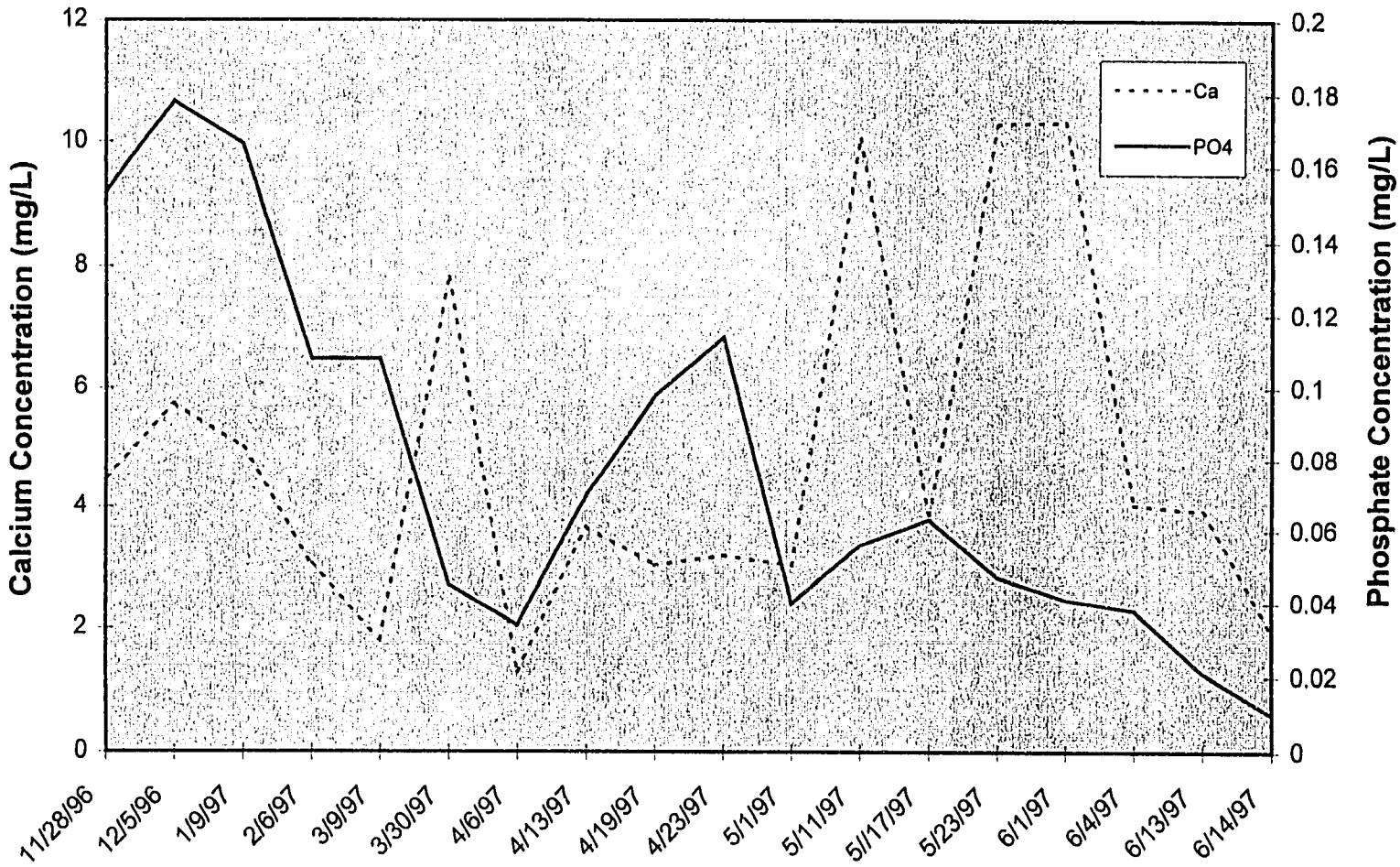


Figure 19
Burn West Sample Station
Calcium vs. Phosphate Concentrations



DISCUSSION

In this study of prescribed burning in the General Creek watershed, burn stations showed greater mean concentrations of all constituents except NO_3^- when compared to control stations. Larger concentrations of Ca^{+2} may have occurred through burning. Although the burn station concentrations were greater, both the burn and control stations showed large concentrations of Ca^{+2}. This may indicate that Ca^{+2} is normally high at this study site. In a wildfire study, Grier (1975) reported the retention of a large amount of cations, which resulted in reduced concentrations of cations entering streamwater. Lower Mg^{+2} and K^+ mean concentrations at both burn and control sites may therefore indicate the retention of cations in soils at the General Creek study site. Saturated cation exchange sites may have caused Ca^{+2} leaching at both burn and control stations. Another prescribed fire study showed the increased mobilization of Ca^{+2} with fire, which created an imbalance at soil cation exchange sites and accelerated leaching of this nutrient (McKee 1982). This finding is supported by the Ca^{+2}, Mg^{+2}, and K^+ concentration results of this master's thesis. Numerous researchers have shown pH increases when soils were exposed to burning (St. John and Rundel 1976; DeBano and Dunn 1982; Agee 1996). Higher pH values increase the affinity of soil colloids for divalent cations such as Ca^{+2} and Mg^{+2}. If pH increased with burning at this study site, this would explain the differences between the burn and control stations, and why the mean concentration of Ca^{+2} increased while Mg^{+2} and K^+ concentrations decreased.

Phosphate showed minor differences in mean concentrations between the burn and control stations (Fig. 8, Fig. 12). Mean concentrations varied by 0.03 mg/L or less. Stark (1977) found that phosphate exhibited similar concentration levels between control and burned sites following a prescribed burn study during a year with high

precipitation. Small increases in PO_4^{-2} were also noted after a prescribed fire study by Gottfried and DeBano (1990). These results are supported by findings of burn and control site comparisons at the General Creek study site. These findings showed such similar concentrations between burn and control sites that burning was not expected to cause these changes. The above normal precipitation and rain-in-snow events which caused high runoff during the study period were presumed to cause the differences in PO_4^{-2} concentrations as this nutrient was leached from soil or ash.

The burn stations exhibited a smaller combined mean concentration of NO_3^- than the control stations (0.2 vs. 0.24 mg/L), which was assumed to occur as a result of volatilization with burning (Fig. 13). Since the mean for burned stations was below the control station mean, prescribed fire and nutrient loading of NO_3^- to surface water from burned stations created no additional impacts to water quality with regards to NO_3^- at this study site.

Sulfate concentrations at the control stations were similar to burn east concentrations (Fig. 8, Fig. 12). The burn west station exhibited a mean SO_4^{-2} concentration much higher than all other stations. However, these concentrations fell off rapidly after rains decreased and flooding subsided at the beginning of 1997. Therefore, the high concentration of SO_4^{-2} was attributed to runoff events and ash leaching which mobilized this nutrient. Since these results occurred under extreme conditions of precipitation and runoff, it was expected that under normal circumstances SO_4^{-2} concentrations would be much smaller.

In general, comparisons of nutrient concentrations between individual control stations demonstrated similar means with no extreme outliers. However, the unburned upstream (above burn east) station mean concentration of Ca^{+2} was almost 2 times greater than at the control east station (4.02 versus 2.1 mg/L) (Fig. 8, Fig. 12).

Significant differences in all constituents except PO_4^{-2} occurred between the upstream (above burn east) station and the control stations. Nutrient concentrations were shown to be significantly different between each of the control sites except for the comparison of control east and control seep stations. Phosphate only exhibited a significant difference between the control east and control west sample stations. These findings of background concentrations were probably a result of site variation since none of these stations were treated with fire.

A comparison of mean nutrient concentrations between the upstream (above burn east) and the burn east stations (Fig. 8) showed smaller constituent concentrations of SO_4^{-2}, PO_4^{-2}, and K^+ at the upstream (above burn east) site. Phosphate concentrations between the unburned upstream (above burn east) and burn east stations were expected to be similar since the comparison of control and burn stations (Fig. 13) revealed minor mean concentration differences of this nutrient. Larger concentrations of Ca^{+2} at the unburned upstream (above burn east) station indicated that differences were not a result of burn effects. Low NO_3^- and SO_4^{-2} concentrations at both sites were probably a result of plant uptake, or loss of these nutrients through volatilization or mobilization.

Since both the burn east and burn west stations were treated with prescribed fire, significant differences in nutrient concentrations were contributed to site variations or differences between the burn treatments at these sites. Variations in site characteristics such as slope and runoff patterns, microclimate, vegetation, or subsurface conditions including soil or substrate, may have contributed to these differences. Individual prescribed fire treatments may have affected the outcome between the burned sites. Variation in treatments may have influenced the mobilization

of nutrients, reduced vegetation uptake of nutrients, or altered transpiration rates at these sites.

Anion and cation mean concentrations at the burn west station were higher than the burn east station. In contrast to the burn east station which is located on relatively flat ground, the burn west sampling station lies on a slightly steeper slope. Runoff moves more quickly through an area of greater slope such as in the burn west watershed, and it is assumed that less nutrient uptake occurred as runoff flowed through this area. This may explain in part the greater mean nutrient concentrations in streamwater sampled at the burn west station (Fig. 8). The result at this sampling station did not support the findings by Richter, Ralston, and Harms (1982) that, following prescribed fire, litter and soil layers filter soluble nutrients from runoff before entering streams. However, prescribed burning at the General Creek study site did not cause above background levels of PO_4^{-2} to be added to the system.

In previous studies, the lack of nutrient increases in streamwater was shown to occur as a result of vegetation uptake once nutrients infiltrated into the soil (Stark 1977; Davis 1989). This soil buffering effect and subsequent uptake of nutrients by vegetation was also noted by McColl and Grigal (1977). At the end of this master's thesis study, PO_4^{-2} concentrations at the burn east station returned to levels noted at the beginning, which indicate losses or uptake and support the above findings. Nitrate and SO_4^{-2} at the burn east station also decreased in concentration by the end of the study. This result shows short-term increases of these nutrients, and decreased loading over time to the General Creek watershed and Lake Tahoe.

Sampling was conducted during winter, spring, and early summer seasons. A dormant period occurred during this study, and sampling did not extend through the entire growing season. Therefore, year-long vegetative effects on nutrient uptake were

not represented with this data set. More work measuring nutrient uptake by plants is necessary to show the effect of vegetation on sites treated with prescribed fire.

Ion exchange may explain the results of Ca^{+2} and PO_4^{-2} observations (Fig. 14-19). In an earlier prescribed burn study, Stark (1977) observed that soil chemical changes following prescribed fire enhanced the retention of phosphate. Many researchers have found that chemical and physical factors of soil contributed to nutrient immobilization through ion exchange on colloid particles, rendering them insoluble (Johnson and Needham 1966; Snyder, Haupt, and Belt 1975; McColl and Grigal 1975; McColl and Grigal 1977; Boerner 1982; Stednick, Tripp, and McDonald 1982). Large amounts of Ca^{+2} that were produced by burning and existed at the control stations, may have influenced subsequent adsorption of this nutrient or other cations to soil particles and may have offered available sites for anion interaction and immobilization. Anion-cation interactions at the edges of soil colloid particles are a possible explanation for the minor occurrence of PO_4^{-2} in stream water. These interactions would immobilize a portion of the PO_4^{-2} in the system, subsequently reducing the amount of PO_4^{-2} entering surface waters, and mitigating water quality impacts to General Creek and Lake Tahoe.

Precipitation influenced the nutrient concentrations found in streamwater runoff for at least a portion of the sampling stations. The study area was under deep snow cover for the duration of the winter and spring between November, 1996 and May, 1997. Heavy rains occurred in December, 1996 and January, 1997. Snowmelt resulted from a large volume of precipitation on top of snowpack conditions. Nutrients were mobilized with these large precipitation events or during snowmelt runoff periods. This resulted in an increase in some nutrients with mobilization, and reduction of other nutrient concentrations through dilution.

Higher concentrations of SO_4^{-2} at the beginning of the study at the burn west station probably occurred after an initial precipitation event. Ash leaching may have occurred, which would account for decreased concentrations later in the study. Greater concentrations of SO_4^{-2}, Ca^{+2}, Mg^{+2}, and K^+ were demonstrated at the burn east and burn west stations during these precipitation events. The control east station showed little movement of anions in January, and greater mobilization in April. Snowmelt runoff in April may have initiated mobilization of these nutrients from soil or a remaining ash layer. Mobilization of nutrients at the control west station on March 18 may have occurred without a dilution effect because there was a lull in precipitation before this date. Additional mobilization and dilution occurred with rain on snow or heavy precipitation events throughout this study.

Ephemeral streams responded similarly to localized rainfall in the General Creek watershed. Nutrient concentrations showed increases and decreases in accordance with hydrograph curves (Fig. 5). A considerable flush of nutrients may have been missed when a rain event was absent and snowmelt was peaking; however, this study captured an adequate range of the snowmelt effects that occurred in the General Creek watershed. Seasonal fluctuations were noted in a study by Davis (1989), where a trend of lower concentrations during periods of high precipitation and increased streamflow occurred. Johnson and Needham (1966) showed the increase of ionic composition in streamwater to be a result of runoff effects causing higher concentration of nutrients to occur during periods of little precipitation and low streamflow. In this study of the General Creek watershed, Ca^{+2} concentrations often exhibited higher concentrations with increased streamflow. In a study area where clearcut and subsequent slash burns occurred, Snyder, Haupt, and Belt (1975) reported an unexpected increase in Ca^{+2} with

high flows. At that site, Ca^{+2} increased during snowmelt and high flows, but no explanation for the circumstance was given.

Water quality of the Lake Tahoe Basin is protected by the Regional Water Quality Control Board of California (Regional Board). Nutrient concentrations of NO_3^-, SO_4^{-2}, and PO_4^{-2} found in this study were contrasted with water quality objectives for total nitrogen, SO_4^{-2}, and total phosphorous set by the Regional Board for General Creek and Lake Tahoe (there are no established criteria for nitrogen and phosphorous fractions or other constituents investigated in this study) and are shown in Table 4.

Both General Creek and Lake Tahoe water quality objectives for total P were exceeded by mean and maximum concentrations of PO_4^{-2} at all sample stations. Each sampling station showed minimum concentrations of PO_4^{-2} below the General Creek and Lake Tahoe criteria. However, General Creek has exhibited total P concentrations greater than the 0.015 mg/L objective in previous years. Other Lake Tahoe tributaries have also exceeded total P objectives (Tahoe Regional Planning Agency 1994). Since PO_4^{-2} values from both the burn and control sites exceeded the criteria for total phosphorous, it was concluded that burning was not responsible for the higher than background levels. This result suggests seasonal events and subsequent leaching as the cause of high PO_4^{-2} concentrations. The heavy precipitation that occurred during the study period may have mobilized PO_4^{-2} from soil or ash. Concentrations exceeding the water quality criteria may have been diluted with the high precipitation that occurred during this study, which may have reduced the effects to General Creek and Lake Tahoe.

Table 4. Anion concentrations at burn and control sites in comparison to water quality objectives set by the California Regional Water Quality Control Board for General Creek and Lake Tahoe. Concentrations are in mg/L.

Sample Station		L.Tahoe	Gen. Ck.		L.Tahoe	Gen. Ck.		L.Tahoe	Gen. Ck.
	NO_3^-	total N	total N	SO_4^{-2}	SO_4^{-2}	SO_4^{-2}	PO_4^{-2}	total P	total P
Burn East n=20									
Maximum	0.29	0.15	0.15	1.02	1.0	0.4	0.22	0.008	0.015
Minimum	0.0	0.15	0.15	0.0	1.0	0.4	0.0	0.008	0.015
Mean	0.03	0.15	0.15	0.35	1.0	0.4	0.07	0.008	0.015
Burn West n=19									
Maximum	2.12	0.15	0.15	15.3	1.0	0.4	0.19	0.008	0.015
Minimum	0.0	0.15	0.15	0.12	1.0	0.4	0.0	0.008	0.015
Mean	0.38	0.15	0.15	5.2	1.0	0.4	0.07	0.008	0.015
Above Burn East (unburned) n=11									
Maximum	0.08	0.15	0.15	0.16	1.0	0.4	0.13	0.008	0.015
Minimum	0.0	0.15	0.15	0.0	1.0	0.4	0.0	0.008	0.015
Mean	0.01	0.15	0.15	0.06	1.0	0.4	0.05	0.008	0.015
Control East n=12									
Maximum	0.77	0.15	0.15	0.93	1.0	0.4	0.17	0.008	0.015
Minimum	0.0	0.15	0.15	0.0	1.0	0.4	0.0	0.008	0.015
Mean	0.25	0.15	0.15	0.27	1.0	0.4	0.07	0.008	0.015
Control West n=16									
Maximum	0.91	0.15	0.15	0.72	1.0	0.4	0.18	0.008	0.015
Minimum	0.0	0.15	0.15	0.28	1.0	0.4	0.0	0.008	0.015
Mean	0.17	0.15	0.15	0.19	1.0	0.4	0.05	0.008	0.015
Control Seep n=17									
Maximum	0.99	0.15	0.15	0.72	1.0	0.4	0.17	0.008	0.015
Minimum	0.0	0.15	0.15	0.0	1.0	0.4	0.01	0.008	0.015
Mean	0.31	0.15	0.15	0.29	1.0	0.4	0.04	0.008	0.015

The Lake Tahoe criterion for SO_4^{-2}(1.0 mg/L) was met by mean, maximum, and minimum concentrations of SO_4^{-2} at all stations except burn west. At this station the maximum concentration value of SO_4^{-2} was over 15 times higher than the objective for this water body; however, the mean and minimum concentrations were below the criteria. The above burn east station showed mean, maximum, and minimum concentrations below the SO_4^{-2} criteria for General Creek (0.4 mg/L). All other stations were below the General Creek objective when comparing mean and minimum concentrations except burn west; only the minimum value at this station was below the criteria. Prescribed burning in the General Creek watershed showed no detrimental effects in terms of SO_4^{-2} entering the system.

Nitrate concentrations were greater than the total N objectives for both water bodies (0.15 mg/L) at all stations with the exception of the upstream (above burn east) station at the burn east unit and the control west station, which showed values below the criteria for General Creek. The Tahoe Regional Planning Agency (1994) demonstrated greater total N than the 0.15 mg/L objective on General Creek in previous years, although higher concentrations were found on other Lake Tahoe tributaries. The maximum value of NO_3^- at the upstream (above burn east) station was 0.16 mg/L, compared to the Lake Tahoe total N criteria of 0.15 mg/L. A mean value of 0.01 mg/L at this station was below the criteria. Since NO_3^- is a fraction of total N, and the concentrations of this nutrient may have decreased as it was added to the system, it was evaluated as meeting the Lake Tahoe criteria. The control west station had a similar NO_3^- value of 0.17 mg/L, and was also considered to meet the total N criteria for Lake Tahoe for the same reasons.

These results indicated that initial concentrations, although higher than the objective at a given point in time, might become reduced as they flow through the

system from ephemeral tributaries. Downstream processes such as dilution, plant uptake, soil adsorption, or ion interactions may effect the fate of these nutrients in the system. This assumption is supported by findings of greater on-site nutrient concentrations compared to off-site nutrient concentrations by Baker (1988). This outcome indicated that soil properties might contribute to the fate of nutrients through a buffering effect. Increases in nutrient concentrations were noted with burning in previous studies, but researchers concluded that the results were unlikely to impair water quality because the increases were insignificant (Johnson and Needham 1966; Campbell et al. 1977; Richter, Ralston, and Harms 1982; Stednick, Tripp, and McDonald 1982; Winzler and Kelly 1982; Gottfried and DeBano 1990).

Additional input of nutrients to Lake Tahoe resulting from prescribed burning in the General Creek watershed either did not exceed water quality criteria, or were not significantly different from control sites. Therefore, this burning is not expected to effect the waters of Lake Tahoe. As a result of the flooding of the Lake Tahoe Basin in January, 1997, and subsequent runoff, elevated concentration of nutrients from this study site may have been diluted by the time these nutrients reached Lake Tahoe, as long as inputs from the remainder of General Creek or other watersheds lacked high nutrient concentrations. In studies by McColl and Grigal, increased concentrations of phosphorous produced no effect on lake water quality due to a large lake to watershed ratio and subsequent dilution that occurred (1975 and 1977). Due to the large size of Lake Tahoe in relation to the Tahoe Basin watershed, a similar outcome may have occurred at this site.

RECOMMENDATIONS

Numerous concerns surround prescribed fire as a management tool in the Lake Tahoe Basin, including whether prescribed fire may further degrade the water quality of Lake Tahoe by increasing nutrient runoff to the Lake. Knowledge of prescribed burn effects on surface waters and sensitive riparian habitats are needed in the Lake Tahoe Basin due to the enforcement of strict water quality regulations and biological thresholds in order to maintain the water quality of the Lake. Despite the need for prescribed burning, the effect of this practice on many forest elements including soils, nitrogen-fixing microorganisms and plants, nutrient loading, and surface water quality remain undetermined (DeBano, Ffolliott, and Baker 1996; Richter, Ralston, and Harms 1982).

Recommendations for prescribed fire management resulting from this study include additional research and comprehensive monitoring of burned sites. Future researchers of prescribed fire and water quality in the Lake Tahoe Basin and other sensitive aquatic ecosystems should consider the inclusion of groundwater and soil water effects for a more comprehensive determination of the fate of nutrients (Baker 1988). The effects of short or long-term changes and immediate or delayed responses need to be evaluated more thoroughly. Off site and downstream effects should also be considered. Although most nutrient concentrations were either below water quality criteria limits or were comparable to control site concentrations in this study of the General Creek watershed, cumulative effects from the DPR prescribed burn program still need to be determined.

Related research topics could include the determination of ash constituent ratios, changes in nutrient solubility, or the role of temperature during precipitation on nutrient effects following prescribed burning. The considerable difference in results found in

studies of prescribed fire and nutrient loading suggests the need for further research in different watersheds under varying conditions. More information needs to be collected within forest stands of differing age classes and between individual species to determine nutrient responses from prescribed burning (Harris and Covington 1983). Furthermore, nutrient fallout from smoke particulate matter or volatilized materials are topics that have not received much attention and may have profound impacts on an ecosystem such as the Lake Tahoe Basin.

Monitoring a treated site is crucial in evaluation of prescribed burn effects. Since stream environments are constantly changing, predictable or definitive results from a monitoring program will be limited. Prescribed burn effects coupled with natural events will determine the outcome of monitoring.

The appropriate duration of a monitoring program will depend on the management goals for a given treatment area. Sampling to obtain at least one full year of seasonal changes would be appropriate. Longer sampling periods may be necessary to capture a full range of data during changes at as site, such as plant uptake of nutrients, microclimate, normal weather patterns, and episodic precipitation events. Variations between site conditions such as slope, aspect, vegetation, microclimate, or other factors may complicate the determination of specific causes of nutrient loading. The following sampling protocol will help alleviate noise within the data occurring with site variation.

Since runoff and streamflow are the mechanism of nutrient transport, precipitation and snowmelt runoff events should be comprehensively monitored to determine the extent of nutrient loading to streamwater. Sites should be sampled either on a routine basis, during episodic runoff events, or both. Regardless of whether a site is studied before and after a burn treatment, or only afterwards at treatment and control

sites, a monitoring program should consider sampling upstream, on-site, and downstream of the treated area to determine the full range of effects from burning.

Parameters to monitor for water quality might include temperature, pH, conductivity, dissolved oxygen, and nutrients. Nutrients that should be targeted include those known or expected to negatively affect the water body of interest. Nitrogen and phosphorous are the primary nutrients of interest for General Creek and Lake Tahoe, because of their link to eutrophication in the Lake. As a result of elevated concentrations of Ca^{+2} and SO_4^{-2} during periods of runoff at the General Creek study site, prescribed fire managers in the Lake Tahoe Basin may also consider monitoring for these nutrients.

Soil and vegetation are intimately connected to water within a riparian ecosystem. Effects to these components from fire and the subsequent interactions with surface and groundwater are important An assessment of existing soil and plant conditions should be considered. Determination of soil types and physical characteristics would offer information about permeability and moisture retention. Comparisons of vegetation cross sections at a site before and after treatment could help evaluate the characteristics and outcome of a given fire. Fire intensity could be determined from vegetation cross section comparison, which would offer information about the site conditions after a burn treatment.

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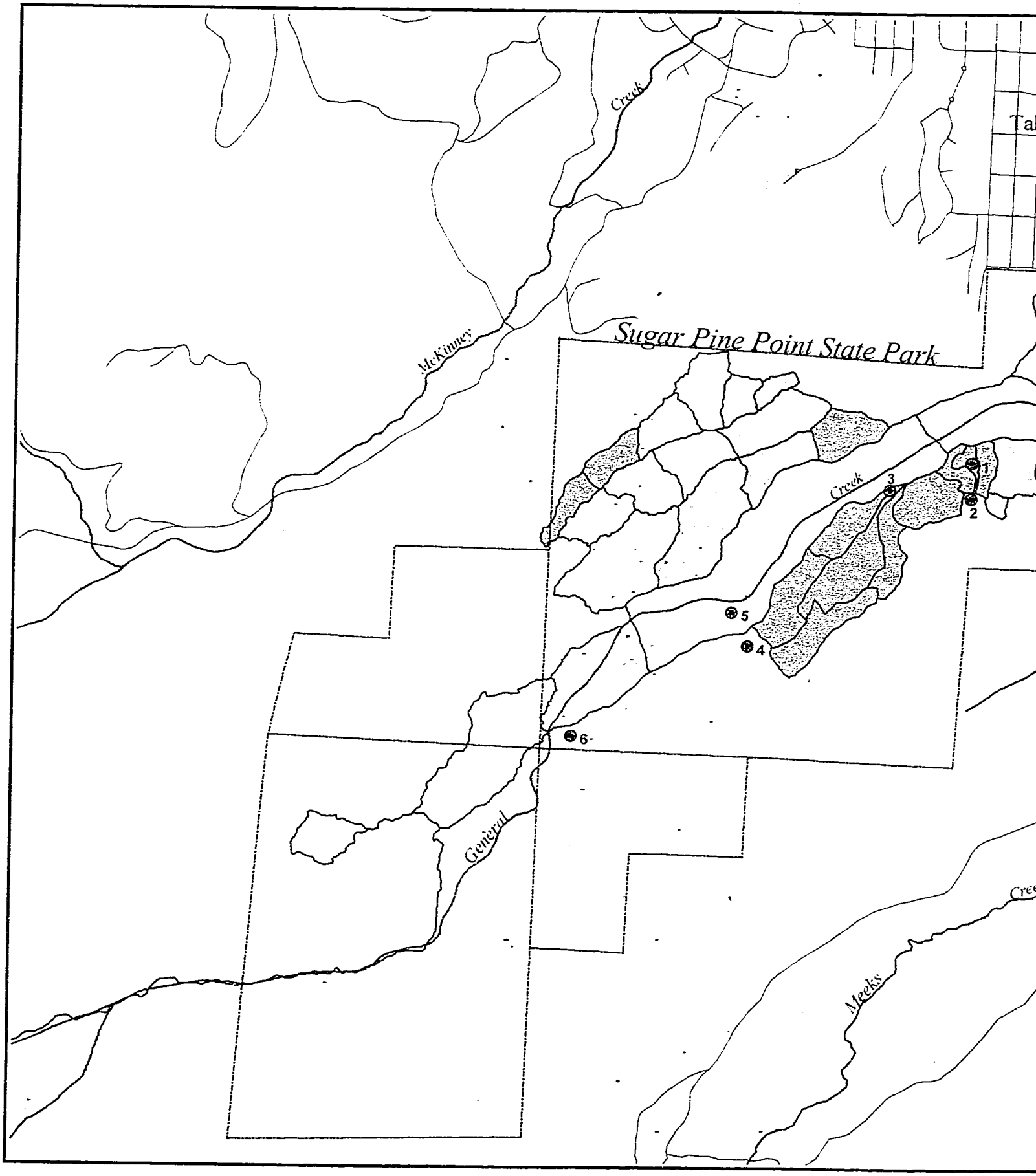
APPENDIX A


Creek
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Sugar Pine Point State Park
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Creek
1
2
3
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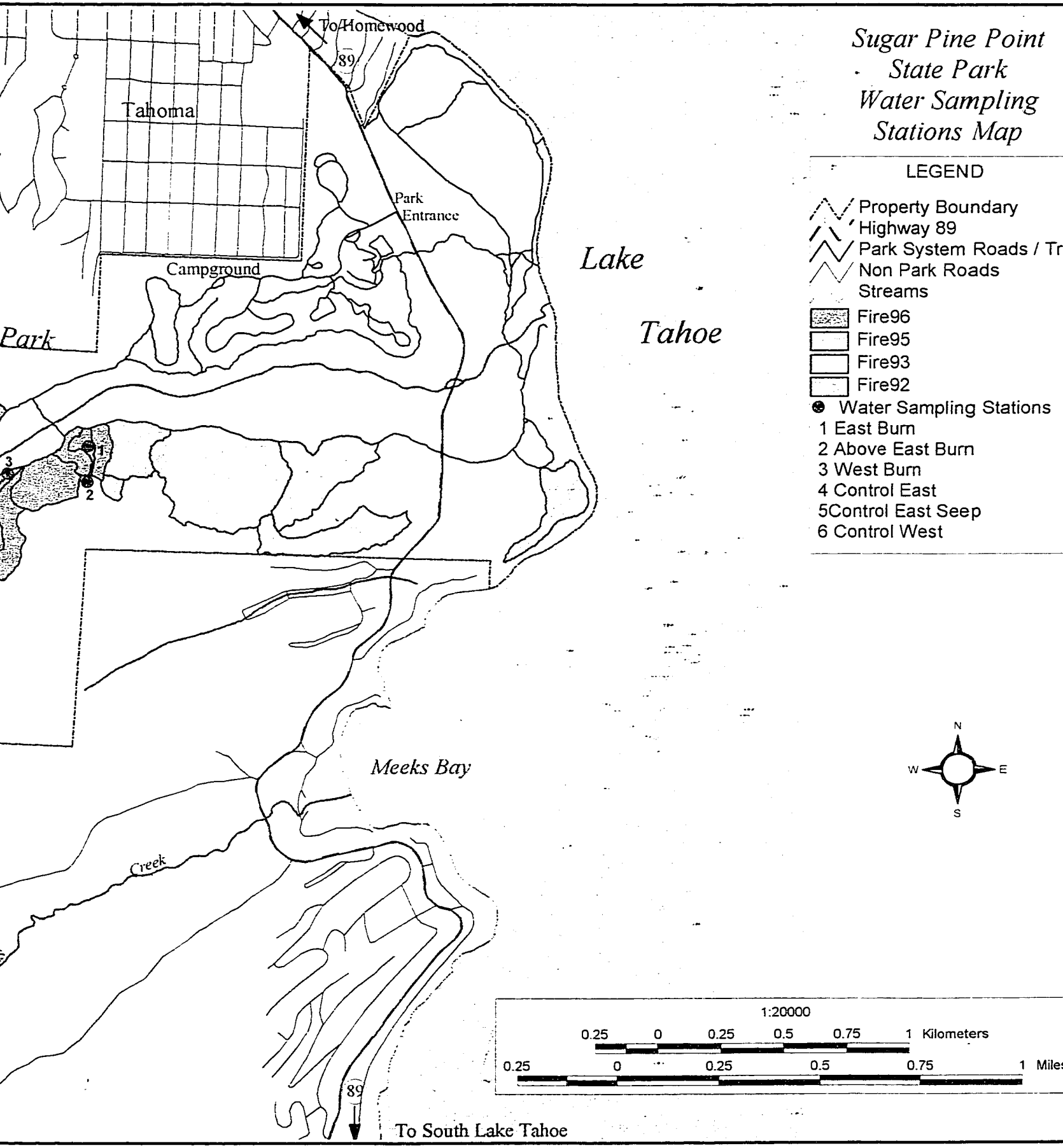
General
Meeks
Cree


To Homewood
89
Tahoma
Park
Entrance
Campground
Lake
Tahoe
Park
1
2
3
Meeks Bay
Creek
89
To South Lake Tahoe
Sugar Pine Point
State Park
Water Sampling
Stations Map
LEGEND
Property Boundary
Highway 89
Park System Roads / Tr
Non Park Roads
Streams
Fire96
Fire95
Fire93
Fire92
Water Sampling Stations
1 East Burn
2 Above East Burn
3 West Burn
4 Control East
5Control East Seep
6 Control West
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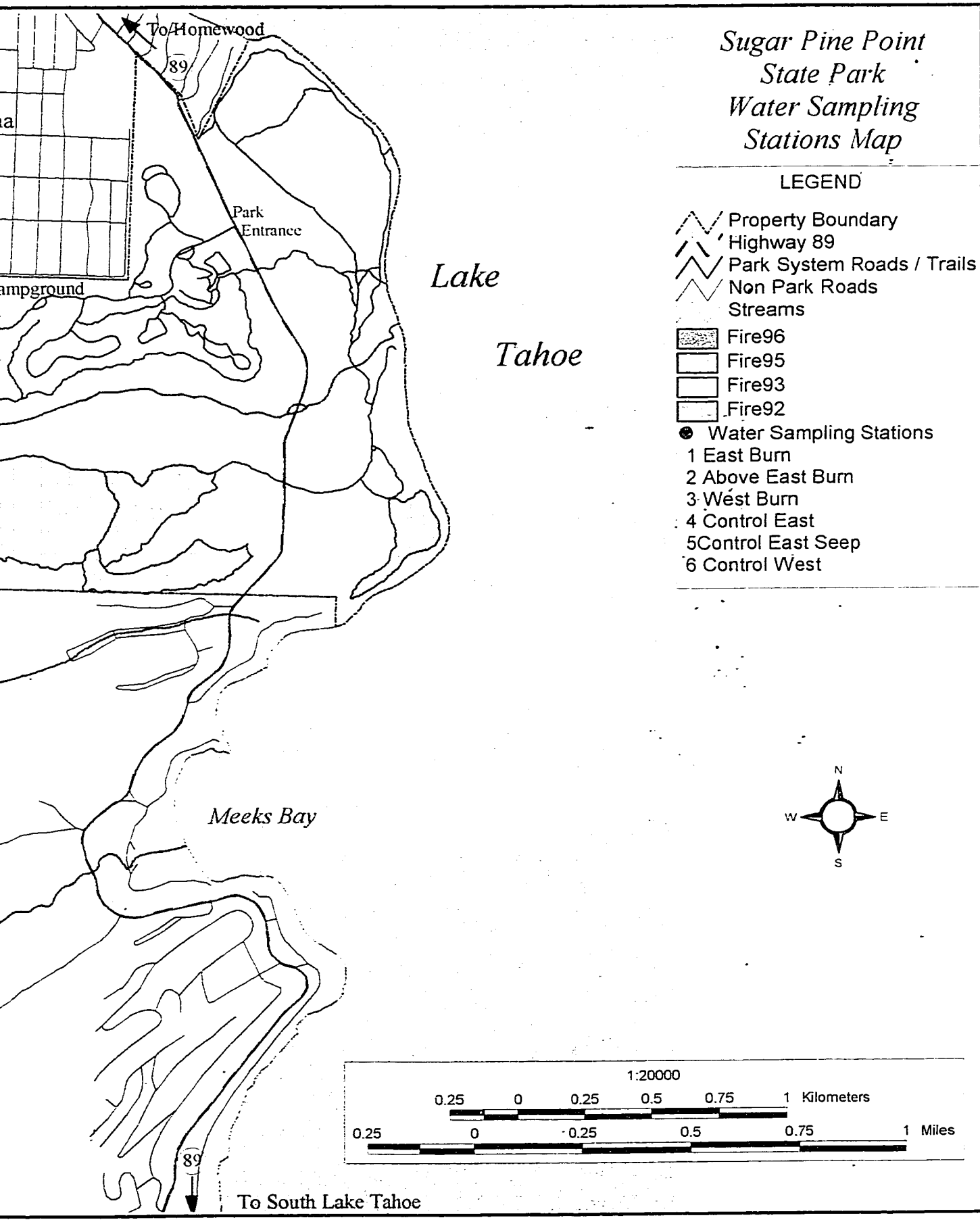


Sugar Pine Point State Park Water Sampling Stations Map

LEGEND

- Property Boundary
- Highway 89
- Park System Roads / Trails
- Non Park Roads
- Streams
- Fire96
- Fire95
- Fire93
- Fire92
- Water Sampling Stations
  - 1 East Burn
  - 2 Above East Burn
  - 3 West Burn
  - 4 Control East
  - 5Control East Seep
  - 6 Control West

DESIGNED | DRAWN | CHECKED

DATE

REVISIONS

RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF PARKS AND RECREATION
SIERRA DISTRICT - RESOURCE OFFICE
GIS/GPS SECTION

PREPARED BY Mandeno DATE 12/02/98

Sugar Pine Point State Park
Water Sampling Stations Map

DRAWING NO
RO127a

SHEET NO. 1 OF 1

APPENDIX B

Appendix B. Water sample chemical analyses results

CONTROL EAST Sampling Station

Date	NO3	SO4	PO4	Ca	Mg	K
11/22/96	0.77	0.37	0 *	*	*	
12/5/96	0.26	0.36	0.15	2.29	0.17	0.4
1/9/97	0.13	0.25	0.1	1.11	2.18	0.52
2/6/97	0	0.12	0.04	1.36	0.16	0.43
3/18/97	0	0.12	0.17	1.45	0.16	0.36
3/30/97	0.12	0.31	0.05	1.08	0.12	0.34
4/6/97	0.35	0.93	0.05	2.99	0.35	0.66
4/13/97	0	0.13	0.07	1.25	0.14	0.32
4/19/97	0	0.09	0.09	1.17	0.12	0.53
4/23/97	0	0.11	0.07	1.26	0.14	0.36
5/1/97	0	0.14	0.07	6.28	0.28	0.36
5/11/97	0	0	0.05	3.71	0.17	0.5

CONTROL WEST Sampling Station

Date	NO3	SO4	PO4	Ca	Mg	K
11/22/96	0.39	0.46	0 *	*	*	
11/28/09	0.87	0.45	0.11	2.56	0.2	0.7
12/5/96	0.16	0.26	0.04	1.92	0.38	0.85
1/9/97	0	0.06	0.09	1.17	0.25	0.4
2/6/97	0	0.05	0.09	1.54	0.34	0.46
3/9/97	0.05	0.06	0.06	0.6	0.11	0.19
3/18/97	0.03	0.07	0.13	1.69	0.34	0.52
3/30/97	0.03	0.09	0.03	1.75	0.36	0.58
4/6/97	0.01	0.04	0.04	1.88	0.32	0.41
4/13/97	0.01	0.03	0.1	1.69	0.32	0.43
4/19/97	0	0.06	0.08	1.86	0.37	0.56
4/23/97	0	0.06	0.15	5.81	0.48	0.53
5/1/97	0	0.02	0.03	1.62	0.32	0.46
5/11/97	0.02	0.18	0.03	4.08	0.5	0.6
5/17/97	0	0.03	0.08	5.6	0.69	0.81
5/23/97	0.05	0	0.04	2.06	0.37	0.71

CONTROL SEEP Sampling Station

Date	NO3	SO4	PO4	Ca	Mg	K
11/28/96	0.98	0.39	0.13	1.8	0.18	0.51
2/6/97	0.12	0.16	0.06	1.47	0.14	0.32
3/9/97	0.47	0.45	0.06	0.8	0.05	0.16
3/18/97	0.29	0.25	0.06	3.77	0.21	0.43
3/30/97	0.17	0.19	0.03	1.56	0.14	0.36
4/6/97	0	0.14	0.08	3.32	0.32	0.38
4/13/97	0.03	0.27	0.07	2.2	0.3	0.45
4/19/97	0.14	0.17	0.09	1.47	0.14	0.3

4/23/97	0.16	0.22	0.09	1.93	0.17	0.39
5/1/97	0.04	0.21	0.02	4.58	0.2	0.33
5/11/97	0.23	0.4	0.03	2.03	0.16	0.39
5/17/97	0.29	0.41	0.03	2.29	0.19	0.42
5/23/97	0.29	0.72	0.01	7.98	0.37	0.38
6/1/97	0.28	0	0.02	2.07	0.16	0.35
6/4/97	0.32	0.26	0.01	2.26	0.18	0.36
6/13/97	0.39	0.3	0.01	3.4	0.18	0.39
6/14/97	0.39	0.32	0.01	2.25	0.19	0.41

BURN EAST Sampling Station

Date	NO3	SO4	PO4	Ca	Mg	K
11/22/96	0	0.51	0 *	*	*	
11/28/96	0.01	0.88	0.13	1.85	0.28	0.65
12/5/96	0	0.67	0.12	2.84	0.41	0.84
1/9/97	0.05	0.35	0.14	5.39	0.41	0.54
2/6/97	0	0.14	0.03	1.77	0.3	0.44
3/9/97	0.07	0.2	0.08	0.99	0.13	0.32
3/18/97	0.01	0.11	0.22	1.77	0.29	0.39
3/30/97	0.03	0.21	0.04	1.84	0.3	0.56
4/6/97	0.18	0.2	0.04	1.65	0.15	0.32
4/13/97	0	0.11	0.06	1.84	0.3	0.38
4/19/97	0	0.1	0.09	1.9	0.3	0.42
4/23/97	0	0.11	0.08	1.9	0.31	0.43
5/1/97	0	0.09	0.05	1.81	0.3	0.38
5/11/97	0	0	0.06	1.98	0.29	0.41
5/17/97	0.29	1.02	0.05	2.05	0.33	0.37
5/23/97	0.09	0.49	0.03	3.74	0.38	0.38
6/1/97	0.06	0.3	0.04	2.25	0.31	0.3
6/4/97	0	0	0.02	2.14	0.3	0.28
6/13/97	0.03	0.2	0.03	2.28	0.32	0.28
6/14/97	0	0.05	0	2.19	0.33	0.32

BURN WEST Sampling Station

Date	NO3	SO4	PO4	Ca	Mg	K
11/22/96	0.41	15.2	0 *	*	*	
11/28/96	0.54	11.3	0.15	4.5	0.5	0.7
12/5/96	0.2	8.26	0.18	5.74	0.66	1.32
1/9/97	0.15	1.34	0.17	5	0.42	0.63
2/6/97	0.29	0.93	0.11	3.04	0.4	0.63
3/9/97	1.02	1.87	0.11	1.8	0.2	0.45
3/30/97	2.12	7.45	0.05	7.82	1.22	1.69
4/6/97	0	0.12	0.03	1.29	0.14	0.36
4/13/97	0.37	0.89	0.07	3.66	0.38	0.67
4/19/97	0.09	0.89	0.1	3.03	0.37	0.77

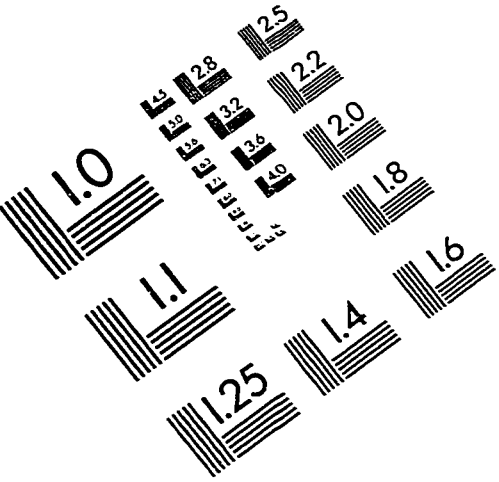
4/23/97	0.08	0.81	0.11	3.19	0.38	0.75
5/1/97	0	0.58	0.04	3.03	0.35	0.7
5/11/97	0.45	1.81	0.06	10.1	0.62	0.8
5//17/97	0.14	0.22	0.06	3.86	0.41	0.64
5/23/97	1.07	4.27	0.05	10.3	0.95	0.68
6/1/97	0.11	0.21	0.04	10.3	0.59	0.46
6/4/97	0.09	0.14	0.04	4.03	0.43	0.47
6/13/97	0.06	0.16	0.02	3.92	0.4	0.47
6/14/97	0.05	0.17	0.01	1.93	0.47	0.56

ABOVE BURN EAST Sampling Station

Date	NO3	SO4	PO4	Ca	Mg	K
4/13/97	0.05	0.1	0.03	1.91	0.31	0.41
4/19/97	0	0.15	0.11	8.13	0.43	0.42
4/23/97	0	0.16	0.13	8.44	0.58	0.45
5/1/97	0	0.08	0.04	1.9	0.31	0.41
5/11/97	0	0	0.04	2.16	0.31	0.41
5/17/97	0	0	0.06	4.22	0.36	0.37
5/23/97	0	0	0.04	2.12	0.3	0.4
6/1/97	0	0	0.04	2.27	0.3	0.3
6/4/97	0	0	0.05	8.56	0.38	0.36
6/13/97	0.08	0.1	0	2.34	0.34	0.39
6/14/97	0	0.05	0	4.22	0.33	0.45

* no sample collected

IMAGE EVALUATION
TEST TARGET (QA-3)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